

DOKUZ EYLÜL UNIVERSITY
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DOCTORAL THESIS
Doctor of Philosophy (PhD)

ESSAYS ON ECONOMIC GROWTH AND HEALTH

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İZMİR- 2022

DECLARATION

I hereby declare that this doctoral thesis titled as “Essays on Economic Growth and Health” has been written by myself in accordance with the academic rules and ethical conduct. I also declare that all materials benefited in this thesis consist of the mentioned resources in the reference list. I verify all these with my honour.



Date

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Signature

ABSTRACT
Doctoral Thesis
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Essays on Economic Growth and Health
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Department of Economics
Economics Program

This thesis contributes to understanding the relationship between economic growth and health. The first chapter develops an augmented Solow model with the government to examine the absenteeism implications of the workforce's poor health status. The empirical part tests the theory-backed convergence equation and provides dynamic panel data estimates for OECD countries. The empirical findings confirm the theoretical results and show that an increase in the number of absent days incurs high costs for countries in terms of reduced productivity, lower savings, and hence lower long-run output growth.

The second chapter examines the impact of health expenditures on long-run capital accumulation and the welfare of households by providing two extended Ramsey models with the government. The results show that increases in personal and public health spending raise capital accumulation and disposable income through their positive externality effects on the labor force, but they also raise concerns about budgets due to their unavoidable increases. The chapter further derives two augmented Solow models to empirically examine the link between health expenditures and economic growth among OECD members and LDCs.

The last chapter empirically explores the nexus between economic growth and adult obesity. The findings provide clear evidence of absolute and faster conditional obesity convergence and show that economic factors, including income inequality and openness to trade, significantly explain the observed trends

in obesity growth among OECD countries. Each chapter provides valuable insights and different perspectives into the critical role that policy can play in promoting health and long-run economic growth.

Keywords: Solow Growth Model, Ramsey Growth Model, Beta Convergence, Sickness Absenteeism, Health Care Expenditures, Adult Obesity.



ÖZET
Doktora Tezi
Ekonomik Büyüme ve Sağlık Üzerine Denemeler
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Bu tez, ekonomik büyüme ve sağlık arasındaki ilişkinin anlaşılmasına katkıda bulunmaktadır. İlk bölüm, iş gücünün kötü sağlık durumunun yol açtığı devamsızlığın sonuçlarını incelemek için hükümetle birlikte genişletilmiş bir Solow modeli geliştirmektedir. Ampirik kısım, teori destekli yakınsama denklemini test ederek, OECD ülkelerine ait dinamik panel veri tahminlerini sunmaktadır. Ampirik bulgular, teorik sonuçları doğrulamakta ve devamsızlık günleri sayısındaki artışın, üretkenlik, düşük tasarruflar ve dolayısıyla daha düşük uzun vadeli çıktı büyümesi açısından ülkelere yüksek maliyetlere neden olduğunu göstermektedir.

İkinci bölüm, hükümetin olduğu iki genişletilmiş Ramsey modeli sunarak sağlık harcamalarının uzun vadeli sermaye birikimi ve hane halklarının refahı üzerindeki etkilerini incelemektedir. Sonuçlar, kişisel ve kamu sağlık harcamalarındaki artışların işgücü üzerindeki olumlu dışsallık etkileri vasıtasıyla sermaye birikimini ve harcanabilir geliri artırdığını, ancak bir yandan kaçınılmaz artışları nedeniyle bütçelerle ilgili endişeleri de artırdıklarını göstermektedir. Bölüm ayrıca, OECD üyeleri ve EAGÜ'ler arasında sağlık harcamaları ile ekonomik büyüme arasındaki bağlantıyı ampirik olarak incelemek için iki artırılmış Solow modeli de türetmektedir.

Son bölüm, ampirik olarak gelir artışı ile yetişkin obezitesi arasındaki bağlantıyı araştırmaktadır. Bulgular, OECD ülkeleri arasında mutlak ve daha hızlı koşullu obezite yakınlaşmasına dair net kanıtlar sağlamakta ve gelir eşitsizliği ile ticarete açıklık gibi ekonomik faktörlerin obezite artışında

gözlemlenen eğilimleri önemli ölçüde açıkladığını göstermektedir. Her bölüm, politika yapıcılarının sağlığı ve uzun vadeli ekonomik büyümeyi teşvik etmede oynayabileceği kritik role ilişkin değerli bilgiler ve farklı bakış açıları sunmaktadır.

Anahtar Kelimeler: Solow Büyüme Modeli, Ramsey Büyüme Modeli, Beta Yakınsaması, Hastalık Devamsızlığı, Sağlık Harcamaları, Yetişkin Obezitesi.



ESSAYS ON ECONOMIC GROWTH AND HEALTH

CONTENTS

APPROVAL PAGE	ii
DECLARATION	iii
ABSTRACT	iv
ÖZET	vi
CONTENTS	viii
LIST OF ABBREVIATIONS	xi
LIST OF TABLES	xiii
LIST OF FIGURES	xv
LIST OF APPENDICES	xvi
INTRODUCTION	1

CHAPTER ONE

IN SICKNESS AND IN HEALTH: SOME THEORY MORE EVIDENCE

1.1. INTRODUCTION	21
1.2. LITERATURE REVIEW	30
1.3. A SOLOVIAN ECONOMY WITH HEALTHY LABOR	46
1.4. EMPIRICAL METHODOLOGY, DATA, AND FINDINGS	56
1.4.1. Empirical Methodology	59
1.4.1.1. Panel Unit Root Tests	62
1.4.1.2. A Dynamic Panel Data Estimator: The System GMM	68
1.4.2. Data	76
1.4.3. Findings	83
1.5. CONCLUDING REMARKS AND POLICY IMPLICATIONS	104

CHAPTER TWO
INVESTING IN HEALTH: MORE THEORY MORE EVIDENCE

2.1. INTRODUCTION	110
2.2. LITERATURE REVIEW	124
2.3. TWO AUGMENTED RAMSEY MODELS: THE WELFARE AND PRODUCTIVITY EFFECTS OF HEALTH EXPENDITURES	135
2.3.1. Personal Health Expenditures	136
2.3.1.1. Households	136
2.3.1.2. Firms	139
2.3.1.3. Market Equilibrium and Steady State	141
2.3.2. Public Health Expenditures	145
2.3.2.1. Households	147
2.3.2.2. Firms	148
2.3.2.3. Market Equilibrium and Steady State	149
2.3.3. A Small Supplement to the Models	151
2.4. TWO EXTENDED SOLOW MODELS: THE EFFECTS OF HEALTH EXPENDITURES ON PRODUCTIVITY	155
2.4.1. Personal Health Expenditures in a Simple Model of Economic Growth	156
2.4.2. Public Health Expenditures in a Simple Model of Economic Growth	160
2.5. EMPIRICAL RESEARCH	162
2.5.1. Empirical Methodology	163
2.5.2. Data	164
2.5.3. Empirical Findings	168
2.6. CONCLUDING REMARKS AND POLICY IMPLICATIONS	185

CHAPTER THREE
A DRIVER FOR HEALTH DECAY: NO THEORY JUST EVIDENCE

3.1. INTRODUCTION	196

3.2. LITERATURE REVIEW	203
3.3. EMPIRICAL MODEL	208
3.4. METHODOLOGY, DATA, AND EMPIRICAL FINDINGS	212
3.4.1. Methodology	214
3.4.2. Data	215
3.4.3. Empirical Findings	219
3.5. CONCLUDING REMARKS AND POLICY IMPLICATIONS	228
CONCLUSION	231
REFERENCES	242
APPENDICES	



LIST OF ABBREVIATIONS

2SLS	Two-Stage Least Squares
ADF	Augmented Dickey-Fuller
AIC	Akaike's Information Criterion
AIDS	Acquired Immune Deficiency Syndrome
ARDL	Autoregressive Distributed Lag
ASR	Adult Survival Rate
BMI	Body Mass Index
CADF	Cross-Sectionally Augmented ADF
CD	Cross-Sectional Dependence
C-D	Cobb-Douglas
CIES	Constant Intertemporal Elasticity of Substitution
CIPS	Cross-Sectionally Augmented IPS
CO₂	Carbon Dioxide
COVID-19	Coronavirus Disease 2019
CRRA	Constant Relative Risk Aversion
CRS	Constant Returns to Scale
D-F	Dickey-Fuller
<i>e.g.</i>	exempli gratia (Latin for "for example")
Eq.	Equation
<i>et al.</i>	et alia (Latin for "and others")
<i>etc.</i>	et cetera (Latin for "and other similar things")
EU	European Union
FAO	Food and Agriculture Organization
FOCs	First-Order Conditions
G20	Group of 20
GDP	Gross Domestic Product
GHO	Global Health Observatory
GMM	Generalized Method of Moments
HIV	Human Immunodeficiency Virus
HT	Harris and Tzavalis

ILO	International Labor Organization
IPS	Im, Pesaran, and Shin
IV	Instrumental Variable
<i>i.e.</i>	id est (Latin for “that is”)
LDCs	Least Developed Countries
LHS	Left-hand side
LLC	Levin, Lin, and Chu
LM	Lagrange Multiplier
MPC	Marginal Propensity to Consume
MPS	Marginal Propensity to Save
MW	Maddala and Wu
NCDs	Noncommunicable Diseases
NPG	No-Ponzi-Game
OECD	Organisation for Economic Co-operation and Development
OKC	Obesity Kuznets Curve
OLS	Ordinary Least Squares
PPP	Purchasing Power Parity
PURTs	Panel Unit Root Tests
PWT	Penn World Table
RHS	Right-hand side
<i>s.t.</i>	subject to
SSA	Sub-Saharan Africa
TFP	Total Factor Productivity
U.S.	United States
UN	United Nations
VIFs	Variance Inflation Factors
WB	World Bank
WDI	World Development Indicators
WG	Within Group
WHO	World Health Organization
WID	World Inequality Database

LIST OF TABLES

Table 1:	Descriptive Statistics	p.81
Table 2:	Results of PURTs – Sample Set 1	p.84
Table 3:	Results of PURTs – Sample Set 2	p.85
Table 4:	System GMM Estimations: Sickness Absenteeism and Control Variables	p.94
Table 5:	System GMM Estimations: Sickness Absenteeism, the Government, and Control Variables	p.95
Table 6:	System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups	p.98
Table 7:	System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups and Control Variables	p.99
Table 8:	System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups, the Government, and Control Variables	p.100
Table 9:	Long-Run Ratios Implied by the Extended Ramsey Models (With and Without Production Externalities)	p.154
Table 10:	Descriptive Statistics	p.167
Table 11:	Results of PURTs for the OECD	p.169
Table 12:	Results of PURTs for LDCs	p.170
Table 13:	System GMM Estimations for OECD Countries: Health Expenditures	p.177
Table 14:	System GMM Estimations for OECD Countries: Health Expenditures and the Government	p.178
Table 15:	System GMM Estimations for OECD Countries: Health Expenditures, the Government, and Control Variables	p.179
Table 16:	System GMM Estimations for LDCs: Health Expenditures	p.180
Table 17:	System GMM Estimations for LDCs: Health Expenditures and the Government	p.181
Table 18:	Descriptive Statistics	p.216
Table 19:	Results of PURTs	p.220

Table 20: System GMM Estimations: Determinants of Obesity p.224
Prevalence

Table 21: System GMM Estimations: Growth Effects of Obesity p.227
Prevalence



LIST OF FIGURES

Figure 1:	Scatter Plots of the Growth Rate of Output per Worker versus Sickness Absenteeism	p.82
Figure 2:	Global Income and Spending on Health	p.111
Figure 3:	Spending on Health by Country Aggregates	p.113
Figure 4:	Health Spending by Financing Source: OECD and LDCs	p.115
Figure 5:	Adult Obesity Prevalence by Income Groups and on a Global Scale	p.197
Figure 6:	Real GDP per capita and Adult Obesity Prevalence in the OECD	p.198
Figure 7:	Top 18 OECD Members: 1975-2016 Average Obesity Rates	p.199
Figure 8:	Scatter Plots of Obesity Prevalence, Income Growth, and the Determinants of Obesity	p.218

LIST OF APPENDICES

Appendix 1:	Derivations of the Extended Solow Model	app. p. 1
Appendix 2:	The Social Planner's Solution for the Extended Ramsey Model with Personal Health Expenditures	app. p. 7
Appendix 3:	The Social Planner's Solution for the Extended Ramsey Model with Public Health Expenditures	app. p. 10
Appendix 4:	The List of Sample Countries	app. p. 13



INTRODUCTION

The phrase “*health comes first*”, only three words, is a cliché and a reality of human life. As a cliché, everyone has heard and used this phrase at least once in their lives, particularly, and ironically, those in poor health. On the other hand, each of us forgets the real meaning of this phrase in the hustle and bustle of our daily lives. As a reality, it directs our priorities in life, reminds us of our biological limits, and will continue to be said as long as humankind exists and rules on this planet. However, the meaning of these three words is bigger than we think and covers broader aggregates. Aside from being the most important and valuable asset in a person’s life, or for this very reason, health is also one of the top priorities for societies, countries, and thus economies. Good health or being healthy is not only central for individuals to live a prosperous, longer, and more active life, but it is also central for societies and country economies to improve their well-being and growth prospects.

Therefore, good health is, or should be, a main aim and also a means for policy-makers who care about and prioritize the well-being of individuals, the interests of society, and the sustainable growth and development prospects of an economy. Unfortunately, more recently, the Coronavirus Disease 2019 (COVID-19) pandemic has reminded us of the above phrase and arguments, making them more meaningful for us and millions of other people around the world. The entire world has witnessed a sudden threat to individuals’ health, which in turn transforms into a public health emergency of international concern by adversely affecting societies, health care systems, and country economies at the end of the day. At this juncture, before starting, I would like to express my endless thanks to all the scientists and health workers who worked at the cost of their lives during the pandemic.

Health can be broadly defined as a state of complete mental and physical well-being that allows people to enjoy all activities in their daily active life. However, its definition has evolved from the past to the present by becoming more comprehensive to include all aspects of human life. In this sense, early approaches to the definition of health express health narrowly as the absence of any disease or disability by focusing only on physical well-being, although the word “health” implies more than that. Over time, the definition of health has been expanded to include not only the absence of

illness but also a state that allows people to sufficiently deal with all the demands of their daily lives. Finally, in 1948, health achieved its modern definition with the constitution of the World Health Organization (WHO), which is more formal and inclusive.

From a more holistic perspective, the constitution of the WHO defines health as *“a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity”* (WHO, 2020a: 1). In 1986, the WHO further revisited and expanded this definition at the first international conference on health promotion held in Ottawa. In this sense, health is redefined as *“a resource for everyday life, not the objective of living. Health is a positive concept emphasizing social and personal resources as well as physical capacities. Therefore, health promotion is not just the responsibility of the health sector but goes beyond healthy life-styles to well-being”* (WHO, 2009: 1). These last two definitions emphasize the positive nature and multiple dimensions of health and introduce the concept of health as a state that enables individuals to establish a balance, both physically and mentally, with the social, physical, and economic environment. In this context, health or health promotion becomes a means for individuals, societies, and countries' economies, not just an end in itself.

Following the developments above, the feature of health as a resource that supports the functioning of an individual in wider society and the economy began to be emphasized over time. In this way, the concept of health, which has been stuck in the realm of medicine, has started to be mentioned in the discourse of other disciplines, particularly in the realm of economics. More recently, health was introduced by the 2030 Agenda of the United Nations (UN) for sustainable development, adopted in 2015. Under the heading “good health and well-being”, health promotion itself has become the third of the 17 goals. This goal includes the promotion of health and well-being for all people, implying the goal of delivering and utilizing increasing economic resources for everyone worldwide by reducing health and economic inequalities. It also implies the growing importance of health as a requirement that will allow the transformation of each world economy to enable sustained economic growth, development, and prosperity. Of course, this economically indispensable importance of health originates from the explicit and mutual link that has existed for years between

health promotion and economic growth. In other words, good health has always been both an output and an input of the economic growth process itself.

As an end product of the economic growth process, population health significantly improves as a result of the increases in income, which allow individuals to have access to and control over many goods and services that promote health. In this sense, there has been a serious global transformation in human health over nearly two centuries, resulting from rising income levels and technological advances (Bloom *et al.*, 2004; Bloom and Fink, 2013). In 1800, average life expectancy at birth was about 28.5 years around the globe, with no upward trend for many subsequent years (Riley, 2005). However, increases in income resulting from the acceleration and spread of the Industrial Revolution and the resulting improvements in sanitation, hygiene, and food availability, as well as the technological and technical improvements in medicine (such as the development of vaccines thanks to Edward Jenner in 1796, the discovery of the germ theory by Louis Pasteur in the 1860s, and the discovery of penicillin by Alexander Fleming in 1928, among others), have paved the way for further improvements in human health. As a result, the average global life span began to rise slowly but steadily in the mid-nineteenth century, jumped to around 65.2 years at the end of the twentieth century (particularly in Europe), and reached about 72.8 years in 2020 (Riley, 2015; World Bank (WB), 2022).

On the other hand, both as a component of human capital and as an input for economic growth, a healthy population is an engine of economic growth. Good health raises gross domestic product (GDP) per capita by raising both labor productivity and the relative size of the labor force (Bloom *et al.*, 2004). Improvements in health directly support the formation and supply of human capital (Van Zon and Muysken, 2001), increase the returns on investments in other forms of human capital such as schooling, skills, and experience (Becker, 2007; Behrman, 1996; Bleakley, 2010; Leslie and Jamison, 1990), raise the rate of savings and hence the investments in physical capital available to an economy (Bloom *et al.*, 2003; Lee *et al.*, 2000), and change the population size and structure (Bloom and Canning, 2000; Desbordes, 2011; Hansen and Lönstrup, 2015; Soares, 2005).

In this sense, several studies have historically explored the growth benefits of health improvements for very long periods of time. For instance, in his impressive

work, Fogel (1990) has argued that the reductions in chronic malnutrition predicate the significant growth rates in income per capita across Europe and the United States (U.S.). He has found that over the years between 1790 and 1980, improvements in nutrition and calorie intake available for work contributed to nearly 30% of the growth in per capita income in Western Europe. The improvements in nutrition and health allow the poor to enter the labor force and raise the intensity of working hours due to the increases in the calories available for work (Fogel, 1994: 386). Similarly, Floud *et al.* (1990) have shown the significant benefits of improved nutrition for the United Kingdom over the period 1750-1980 by arguing that height status is a robust proxy of nutritional status. More recently, Arora (2001) has shown that over a period of about 100-125 years, improvements in health significantly increased the rate of income growth by about 30%-40% among industrialized countries (Arora, 2001: 699).

In the realm of economics, the considerable contribution of good health to human capital and hence economic growth has been emphasized and known for a long time. The use of the term “human capital” is based on the work of Mincer (1958), but the theory of human capital formation has been largely pioneered by the study of Schultz (1960). Schultz (1961, 1962) is among the first to mention the health and education components of human capital as the prerequisites of impressive economic growth.¹ On the other hand, Becker (1962, 1964) and Mushkin (1962) have stressed the neglected role of health as a form of human capital investment that contributes significantly to productivity gains. The seminal study of Arrow (1963), which gave rise to health economics as a separate discipline, provides the first conceptual distinction between health and other goods. The pioneering studies of Grossman (1972a, 1972b), which draw on some basic notions of household theories provided by Becker (1965, 1967) and Ben-Porath (1967), gave rise to the demand-driven theoretical analysis of health care goods and services.

This theoretical analysis has been further expanded and studied by a number of researchers, including Cropper (1981), Muurinen (1982), Dardanoni (1986), Wagstaff (1986), Forster (1989), Ehrlich and Chuma (1990), Aronsson *et al.* (1994), Johansson and Löfgren (1995), and Meltzer (1997), among others. As a result, a number of studies

¹ The recognition of health as a form of human capital dates back to 1842, when Sir Edwin Chadwick mentioned threatening the human being simply as a capital investment (Mushkin, 1962: 150).

have started to emerge to empirically test Grossman's (1972a, 1972b) model of health demand by using microdata from household surveys (Erbsland *et al.*, 2002; Gerdtham *et al.*, 1999; Leu and Gerfin, 1992; Nocera and Zweifel, 1998; Wagstaff, 1993). Simultaneously, from a microeconomic standpoint, the idea that health has a significant impact on labor outcomes, particularly on productivity and earnings, has begun to emerge as a set of empirical regularities. In this sense, several studies have demonstrated that poor health is associated with significant decreases in wages and earnings in developed countries (Bartel and Taubman, 1979; Chirikos and Nestel, 1985; Contoyannis and Rice, 2001; Luft, 1975). On the other hand, the studies of Latham (1976), Brooks *et al.* (1979), Wolgemuth *et al.* (1982), Strauss (1986), and Schultz and Tansel (1997) have drawn attention to considerable gains in worker productivity resulting from nutritional supplements and reported that poor health significantly erodes the capacity of workers in low-income countries.²

On the other hand, growth economists have started to acknowledge the contribution of human capital to economic growth. Starting in the 1950s, most of the growth studies have argued that the growth in the physical units of the traditional inputs, including capital, labor, and land, failed to explain modern economic growth, even in industrially advanced countries. At first, the missing pieces in explaining income growth were named as the intertemporally separable utility function by Ramsey (1928), the elements of Keynesian analysis by Harrod (1939) and Domar (1946), an index of our ignorance by Abramowitz (1956), the quality of nonhuman capital by Solow (1956) and Swan (1956), the technical change by Solow (1957), and finally, the endogenous optimization of the consumers' savings by Cass (1965) and Koopmans (1963) that built on Ramsey's (1928) work. Therefore, in the framework of the neoclassical tradition, growth theories in the late 1950s and 1960s typically assumed the existence of exogenous technological progress while ignoring human capital.³ However, in the following years, especially after the mid-1980s, research on

² Strauss and Thomas (1998) and Thomas and Frankenberg (2002) have examined the impact of nutrition, adult stature, and calorie intake on productivity and earnings and provided an excellent literature review based on previous microeconomic evidence.

³ In this sense, one exception was the study of Nelson and Phelps (1966). In their study, Nelson and Phelps (1966) assumed that education speeds the process of technological diffusion and hence enters into the function of technology as a parameter that shows human capital intensity.

economic growth regained interest and experienced a boom, beginning with the pioneering studies of Romer (1986) and Lucas (1988).

In the studies of Romer (1986) and Lucas (1988), which were further based on the works of Arrow (1962) and Uzawa (1965), economic growth has started to be explained by an endogenous mechanism. Capital goods were extended to include human capital, whose accumulation is associated with increasing returns, according to Lucas (1988). Hence, in these models, the tendency for diminishing returns to the accumulation of capital is avoided due to the existence of knowledge spillovers and externality effects of human capital (Barro and Sala-i-Martin, 2004). Following them, several studies on economic growth have started to examine the role of human capital in the form of education, including Romer (1990), Becker *et al.* (1990), Rebelo (1991), Sala-i-Martin and Mulligan (1995), Mulligan and Sala-i-Martin (1997), and Jones and Manuelli (1999), among others. While the preceding studies usher the growth community into a new era of endogenous growth models, one implication of Lucas' (1988) study ironically revived a research framework that had died in the early 1970s: neoclassical research on growth.

Lucas' (1988) assumption that human capital should be factored into production functions alongside other traditional inputs resulted in the emergence of a massive number of studies by re-adopting a neoclassical growth framework, which has lost its effectiveness due to a lack of empirical relevance. In this context, one of the main predictions and empirical research areas revealed by the neoclassical growth theory is the premise of β -convergence, which was first introduced by Barro and Sala-i-Martin (1990). According to the neoclassical growth theory, the per capita income growth rate tends to be inversely related to the initial level of per capita income, given the existence of diminishing returns to the accumulation of physical capital. This hypothesis, called absolute β -convergence, assumes that the convergence of an economy depends only on the initial value of per capita income. In a cross-country context, its existence implies that the parameters determining steady-state income levels are the same among the countries. Baumol (1986) and Abramovitz (1986) have been among the first proponents of this hypothesis.

However, in a short time, the hypothesis of absolute income convergence was rejected primarily by the studies of De Long (1988) and Baumol and Wolff (1988) and

further developed by the studies of Barro (1991) and Barro and Sala-i-Martin (1992). These studies have argued that the rich and poor countries may not converge to the same steady-state level of per capita income. In contrast, they have given rise to the hypothesis of conditional β -convergence, suggesting that the initial per capita income levels of the countries converge to the same per capita real income level in the long run only after controlling for some structural differences between countries. In other words, this refers to the convergence of per capita real incomes of countries whose parameters determining the steady-state level of income are similar. Thus, there is no need to distinguish between absolute and conditional convergence when all world economies have the same long-run equilibrium value of per capita income. Following that, numerous studies have revealed that, as predicted by the conditional convergence argument, the per capita incomes of structurally similar countries or regions converge in the long run (Barro and Sala-i-Martin, 1991, 1992a, 1992b, 1995; Sala-i-Martin, 1994, 1996a, 1996b).⁴

Returning to the issue at hand, following the seminal contributions of Barro (1991) and particularly Mankiw *et al.* (1992), the predictions of neoclassical growth started to be re-examined by including human capital in the form of education within the scope of the Solow (1956) model and its income convergence argument. Barro (1991) has developed an *ad hoc* regression approach to empirically test the conditional income convergence hypothesis by including human capital among the other determinants of per capita income growth. On the other hand, the work of Mankiw *et*

⁴ There are basically three types of convergence concepts widely used in the related literature. First, there is the above-explained β -convergence concept, which is further divided into absolute and conditional convergence hypotheses. On the other hand, there is σ -convergence hypothesis, named after the study of Barro and Sala-i-Martin (1990), which deals with the dispersion of the cross-sectional distribution of per capita income. That is, its existence implies a decrease in the variance of the differences between the per capita real incomes of a group of economies over time. In this sense, β -convergence is a necessary but not sufficient condition for σ -convergence (Sala-i-Martin, 1996a, 1996b). Some important contributions discussed σ -convergence include Dowrick and Nguyen (1989), Barro and Sala-i-Martin (1991, 1992b), Friedman (1992), and Quah (1993, 1996). Lastly, there is also the concept of club convergence, which is based on the studies of Baumol (1986), Durlauf and Johnson (1995), and Galor (1996) and relates to multiple equilibrium instead of a unique one as in β -convergence, *i.e.*, each economy may approach a different long-run equilibrium. Among these concepts, an enormous body of literature has emerged on the concept of β -convergence. In comparison to other concepts, its popularity may result from its policy relevance, as it allows for the simultaneous testing of the determinants of income growth and the hypothesis of convergence, and it can also be formally derived using a neoclassical modeling framework. This thesis is also focused on the concept of β -convergence in each of its chapters. Therefore, the discussion here includes only the studies on β -convergence.

al. (1992) has appeared as the first that successfully augments the Solow (1956) model by including human capital in the production function with other traditional inputs. In this manner, Mankiw *et al.* (1992) have established a formal empirical framework for convergence testing in their studies. In their findings, both studies have shown that per capita income levels conditionally converge among countries with similar levels of technology and stocks of physical and human capital in the form of education. Hence, once the standard neoclassical framework is extended to include human capital, a vast body of literature has emerged on convergence conditional on human capital (Barro and Sala-i-Martin, 1992a; Benhabib and Spiegel, 1994; Cohen, 1996; Ding and Knight, 2009; Evans and Karras, 1996; Hoeffler, 2002; Islam, 1995; Knight *et al.*, 1993; Levine and Renelt, 1992; O'Neill, 1995). The findings of these studies have emphasized the significant role of human capital in the form of education as one of the major attributes that explain long-run growth and real income differences across countries.

For a long time, health was largely ignored as an essential component of human capital in the early discourse of growth studies. In this respect, Knowles and Owen (1995) were the first to attract interest to the missing health component of human capital, following the pioneering work of Mankiw *et al.* (1992). In their study, Knowles and Owen (1995, 1997) further expanded the canonical Solow model by including health and education as separate production inputs.^{5,6} In this way, they have paved the way for formal growth regressions to empirically examine the implications of population health on income growth and the convergence process. Following Knowles and Owen (1995, 1997) or the modeling approach of Mankiw *et al.* (1992), one group of studies has used formal regression by augmenting the Solow model to assess the impact of health on the cross-country income convergence process (Heshmati, 2001; Li and Huang, 2009; McDonald and Roberts, 2002; Rivera and Currais, 1999a, 1999b; Webber, 2002). On the other hand, an enormous body of research has relied on *ad hoc* regressions, following the study of Barro (1991), and covered a large part of the empirical research on neoclassical growth (Barro, 1996a;

⁵ There were also other initial efforts that have explored the long-run effects of AIDS on economic growth using a standard neoclassical framework (Cuddington, 1993; Cuddington *et al.*, 1994).

⁶ Other notable exceptions include Morawetz (1977), Hicks (1979), and Wheeler (1980), who were among the first to explicitly consider health in their cross-country regressions under the concept of basic needs, which includes nutrition, life expectancy, infant mortality, and literacy rates.

Barro and Lee, 1994; Bhargava *et al.*, 2001; Bloom *et al.*, 1998, 2004; Bloom and Williamson, 1998; Eggoh *et al.*, 2015; Gallup and Sachs, 2000; Gyimah-Brempong and Wilson, 2004; Hamoudi and Sachs, 1999; Madsen, 2018; Sachs and Warner, 1997).

Ever since, the role of health has become a serious focus of growth inquiry. Other theoretical efforts have emerged to incorporate health human capital into the growth modeling. In an extended neoclassical framework, the studies of Barro (1996b) and Muysken *et al.* (1999); in an endogenous growth framework, the works of Van Zon and Muysken (2001, 2003); and in a Schumpeterian growth framework, the studies of Howitt (2005) and Madsen (2012) have all been among other significant theoretical contributions that examine the interaction between health and economic growth. Other researchers have also provided significant theoretical and empirical contributions to the related research (Acemoglu and Johnson, 2007; Bloom *et al.*, 2004, 2014; Chakraborty, 2004; Jamison *et al.*, 2005; Mayer, 2001a; Shastry and Weil, 2003; Weil, 2007). In addition, once the positive benefits of good health status on economic growth were recognized, growing expenditures on health care as the key source of investments in health capital were justified and became another focus of health research.

Several researchers have attempted to explain the interplay between optimal choice of health expenditures, economic growth, and longevity in an overlapping generations framework (Agénor, 2015; Bhattacharya and Qiao, 2007; Chakraborty, 2004; Chakraborty and Das, 2005; Kuhn and Prettnner, 2016), while others have attempted to explain the incredible increase in health expenditures of the U.S (Dalgaard and Strulik, 2014, 2017; Hall and Jones, 2007). Using human capital-based growth models, either including only health or both components of human capital, growth researchers also theoretically contribute to the understanding of the effects of health expenditures on long-run income growth (Barro, 1996b; Gong *et al.*, 2012; Hosoya, 2002, 2003; Muysken *et al.*, 1999; Van Zon and Muysken, 1997, 2001, 2003). To sum up, the impact of health and its components on economic growth has now been recognized in economic growth theory for more than two decades. The growth literature, one way or another, has shown the sizable productivity and growth returns of better health, attempted to explain the link between health care expenditures

incurred to improve health status and income growth, and also reported that poor health status, proxied by some specific diseases such as the HIV/AIDS epidemic (Ainsworth and Over, 1994) and the prevalence of malaria (Gallup *et al.*, 1999; Gallup and Sachs, 2000; Hamoudi and Sachs, 1999), significantly explains the lower income growth rates of low-income countries.

Then, what's left to be told? As stated by Bloom *et al.* (2018), overall, there are still some problems and deficiencies in examining the impact of health on economic growth. First, the link between health and economic growth changes depending on the dimension of health measured (mortality or morbidity), and particularly on the age structure of the population in question (Bloom *et al.*, 2018: 3). There are an enormous number of studies in the literature that have concluded that “*better health enhances economic growth*”, but there are few efforts to examine and understand “*health in terms of what enhances economic growth*”. There are still no satisfactory data to measure the consequences of poor health status, such as the morbidity rate. Almost all related works in the literature have measured better health primarily through increases in life expectancy at birth and decreases in infant or under-five mortality rates, regardless of the dependent variable and country group in question. In other words, although most of these studies aim to explore the productivity implications of health, they have used health indicators that reflect the health level of the population instead of the working-age population, which are not relevant for productivity measurement (Arora, 2001; Jamison *et al.*, 2005).

Second, there are still crucial differences between the growth effects of health improvements in low- and high-income countries, and the evidence for high-income countries is still skeptical and controversial (Bloom *et al.*, 2018). Given the high aging and better longevity outcomes of high-income countries, new research is required to investigate the productivity effects of health to develop better policy responses for this country group, *e.g.*, by employing health proxies that are more appropriate for high-income countries, such as measures of functional status (Tompa, 2002: 190-197). Third, most of the related studies have included schooling variables in their regressions to simultaneously assess the growth impacts of health and educational human capital. However, as stated by Arora (2001), in most cases, it is hard to ascertain whether the robust growth effects are generated by health or schooling variables due to the high

collinearity between the two. As a prerequisite to producing other components of human capital, such as skills, knowledge, and education, health variables have stronger growth effects, while the growth effects of schooling variables mostly appear to be weak and fail to provide the key aspects of human ability as well (Arora, 2001). Therefore, there may be a need to consider the impact of health variables in more detail and with more robust methodological approaches.

This last point gives rise to another deficiency in the previous literature. Fourth, the methodological approaches used in previous studies raise some serious estimation issues. Most of the related literature has relied on cross-sectional or static panel data approaches in their empirical analyses, which are suspicious both from an econometric and an empirical growth perspective. Therefore, these studies seriously suffer from limited time variation in the data, unobserved heterogeneity bias, and a serious endogeneity that exists between health and growth variables. Although there are a few attempts to resolve these issues by using various approaches, such as the Instrumental Variable (IV) approach, Two-Stage Least Squares (2SLS), and difference Generalized Method of Moments (GMM), these attempts cannot simultaneously address the above issues; rather, they suffer from serious finite sample bias and poor instrumentation problems in short panels, as mostly used by the growth literature (Blundell and Bond, 2000; Blundell *et al.*, 2001; Eberhardt and Teal, 2011; Mátyás and Sevestre, 2008; Temple, 1999).

Given the empirical issues above, there are also some theoretical shortcomings as well. The bulk of the related literature discusses the nexus between health and growth under the standard neoclassical framework that mainly guides the convergence literature. However, there are only a few studies that have examined this nexus based on a formal theoretical derivation. In other words, most of the previous studies in the related literature lack a clear link to the theory, which makes it difficult to properly explain the growth impacts of the coefficients of interest (Bloom *et al.*, 2004; Temple, 1999). On the other hand, the studies that are based on a theoretical framework are most related to the extensive literature of human capital-based growth models. In their theoretical works, they have all employed the same health capital (H) equation ($H = I_H - d(H)$), which is basically formulated as a function of health investments (I_H) and an unknown depreciation rate for health ($d(H)$). In other words, in each case,

they have integrated the health capital (*i.e.*, the health status, H) into the usual aggregate production function, regardless of whether they aim to empirically analyze the growth impact of health status, health care expenditures, or a specific disease. In light of these shortcomings, it seems highly worthwhile to try and explore the matter further with more theoretical works offering different assumptions, more precisely defined parameters, and more accurate indicators of health (Caselli, 2004: 33).

This thesis contributes to understanding the link between economic growth and health. The thesis takes a particular position and provides three essays, each of which deals with one component of the health capital equation in detail, $H = I_H - d(H)$. This thesis aims to explore the link between economic growth and the labor force implications of good health status (H) in Chapter 1, expenditures in health care as a key component of health investments (I_H) in Chapter 2, and weight-related health status as a risk factor for the deterioration of general health status $d(H)$ in Chapter 3. In summary, Chapter 1 develops two augmented Solow (1956) models, one with and one without government, and tests the resulting theory-backed output convergence equations. Chapter 2 derives two extended Ramsey (1928) models with the government (and some further extensions of these two models) and two parallel augmented Solow (1956) models with the government to run several formal convergence regressions on per capita income growth. Chapter 3 provides two empirical models and their estimations examining the nexus between per capita income growth and poor weight-related health status proxied by adult obesity, which is prioritized as a main target for global disease prevention by the WHO. Each chapter provides a few novelties and significant contributions to its related literature, as follows:

Under the title “*In Sickness and in Health: Some Theory More Evidence*”, Chapter 1 aims to explore the effects of a healthy labor force on long-run output growth and the convergence process in a narrowed Solovian framework, which is narrowed in the sense that it sensibly employs only healthy workers in a country. In other words, the theoretical model of Chapter 1 assumes that a country’s production function includes only healthy workers at any instant of time by emphasizing the implications of sickness absence in the production process. At the end, the chapter derives a theory-backed convergence equation that highlights the difference between healthy and

unhealthy workers that are absent from work due to ill health. Thus, from a macro perspective, the chapter both theoretically and empirically addresses the workforce's absenteeism due to ill health, which has been examined only in a few micro-based studies before. Chapter 1 further extends the former model with the existence of a generous government, whose expenditures are endogenously covered by income taxes and have a positive externality effect on the whole production process. For each model, the chapter provides the steady-state solutions of the models and derives two convergence equations conditional on the traditional determinants of Solow growth, the share of healthy workers in the total workforce, and the fiscal policy variables.

The empirical part of Chapter 1 provides system GMM estimates to examine the implications of a healthy labor force on output growth and the convergence process among the countries of Organisation for Economic Co-operation and Development (OECD), for which the empirical evidence is still limited and controversial. In this sense, the share of healthy working hours in total working hours is used as a proxy for a healthy workforce, and absent days due to ill health are used to show the robustness of the original data in the empirical analyses. Moreover, age-specific measures of life expectancy ranging from 15 to 60 and the adult mortality rate between ages 15 and 60 as a proxy for the health status of the working-age population are included in the empirical analyses. The estimations further include fiscal policy variables in line with the extended theoretical model and also control variables, including human capital in the form of education and openness to trade, to partly eliminate omitted variable bias in the analyses. The empirical findings of the chapter confirm the theoretical results and provide valuable insights into the critical role that policy can play in promoting workforce health, ultimately productivity, and long-run output growth. Following that, the study in Chapter 1 contributes to the related literature as follows:

From a theoretical standpoint, first, this study significantly departs from the *ad hoc* empirical studies, which cover a large part of the related literature but lack a formal theoretical derivation. This study uses a theory-based approach to convergence modeling by providing a clear link between the theory and empirics of growth. Second, by directly focusing on the absenteeism implications of poor health, this study further deviates from the related studies that were pioneered by Knowles and Owen (1995) and have used a theory-based approach. In this sense, previous studies, though

exploiting the well-established Solow framework, all mimic the same health human capital accumulation equation in their theoretical parts. However, this study clearly departs from Mankiw *et al.* (1992)-type human capital modeling and defines healthiness over a country's total workforce by giving particular attention to sickness absence. To my best knowledge, there is only one study in the related literature that suggests a distinction between healthy and unhealthy workers in growth modeling. In this sense, Muysken *et al.* (1999) were the first to come up with the idea and to have theoretically examined the trade-off between optimal health expenditures, consumption, and physical capital by adding a healthy workers' accumulation function into the Ramsey growth model. Building on a similar spirit but unlike Muysken *et al.* (1999), this study focuses on the growth and convergence effects of a healthy labor force by using a Solovian setup with the government, which generates a positive externality on the aggregate production process, and empirically tests the derived output convergence equations.

From an empirical perspective, third, the study differs from other studies by means of the methodology employed. This study employs a dynamic panel data estimator, the system GMM, to eliminate the shortcomings of the methodological approaches used in previous studies. Earlier studies in mainstream literature extensively used unreliable techniques to estimate their theory-backed convergence equation, which are not suitable for the dynamic nature of the convergence specification. These previous approaches suffered from a limited time variation in the growth variables, the omission of the unobservable factors, the issue of endogeneity, finite sample bias, and a weak instrument problem. Therefore, the methodology used in this study ensures that we obtain more precise and unbiased estimates of Solow-convergence variables compared to those that have been employed in the earlier studies (Bond *et al.*, 2001). Fourth, this study uses a few health indicators specific to the working population of a country that are different from those that have been used in previous studies.

Most of the related works in the literature have typically used two crude measures of health, life expectancy at birth and infant or child mortality, though they have aimed to examine the productivity implications of health. However, these indicators capture the health level of the entire population, including the dependent

population. Thus, by completely excluding unhealthy workers that are absent from work due to ill health, this study uses several proxy measures for the share of healthy workers in the total workforce. In this sense, to my best knowledge, this study is the first in related literature that uses aggregate data on health-related absence from work. Instead of using population-level measures of longevity and mortality as in previous studies, the study employs two additional indicators to proxy for the health status of a country's most productive age span: life expectancy at specific ages ranging from 15 to 60 and the adult mortality rate between ages 15 and 60. Lastly, compared to other studies, this study uses more recent data over a relatively long period of time to properly explore the impacts of health on the out-of-steady-state dynamics of per-worker output.

Under the heading *“Investing in Health: More Theory More Evidence”*, Chapter 2 investigates the relationship between health expenditures and economic growth in an extended neoclassical growth framework. In this chapter, I provide two augmented Ramsey models to examine the effects of personal and public health spending on capital accumulation, total income, and the welfare of households. Each Ramsey model reasonably assumes that personal health expenditures are inevitable and enter the utility function of households by becoming a part of the endogenous trade-off between consumption and savings. The second model further extends the first model by including tax-financed public health spending in the felicity function of the households. In other words, the second model considers endogenously determined public health expenditures, which are financed by a distortionary income tax on output. Therefore, in each model, both total personal and government spending are subject to a key distinction between health and non-health consumption, which has further implications on individuals' savings. Moreover, each Ramsey model considers the effects of a positive externality generated by health expenditures on the effective labor force. However, the first model presumes that it is the personal health spending of the households that generates this externality, while the second model considers the externality effect generated by the public.

In each model, I further assume the existence of a positive population and technological growth. The chapter directly focuses on long-run equilibria and provides the steady-state solutions of all model variables by using both market and social

planner solutions. In the absence of externalities, the two solutions coincide as each agent continues to consume, produce, and accumulate according to market prices. Lastly, I provide a few extensions to the above models to make their findings somewhat comparable and to provide further implications on the effects of health expenditures. Briefly, the results of the theoretical models suggest that, under the gross substitutability between health and non-health consumption, public health expenditures may help households establish a more balanced trade-off between quantity and quality of life. Moreover, although income taxes introduce inefficiencies due to their distortionary nature, the existence of public health spending de-escalates the adverse impacts of income taxation on capital accumulation and disposable income. In the absence of production externalities, each resource used for public health services directly lowers long-run capital accumulation and presses the budgets of all actors in an economy, while each resource used for personal health spending directly lowers the quality of life for consumers.

In Chapter 2, I further provide two more augmented Solow models in an effort to empirically test the effects of health expenditures on income growth and the convergence process. In other words, two augmented Solow models with the government are further derived in the study to run theory-backed income convergence regressions conditional on the health expenditures provided by different financing sources. As in Ramsey models, each Solow model considers the distinction between health and non-health consumption. That is, both models are derived by alternately highlighting the effects of personal and public expenditures on income growth. Furthermore, in parallel to the Ramsey models, the first model considers the externality effect of personal health expenditures on the labor force, while the latter deals with the externality generated by public health spending. However, in this case, each Solow model endogenizes personal and public health expenditures by assuming that they take a constant share from disposable and total income, respectively. In the Solow framework, unlike augmented Ramsey models, public health expenditures free the savings rate from the detractive effects of personal health spending. Furthermore, all models seriously imply a costly trade-off for both consumers and the public.

The empirical part of the chapter provides dynamic panel data estimates for two theory-based convergence equations. Moreover, the study examines the nexus

between health spending and income growth for two polar country groups—OECD members and least developed countries (LDCs)—which are quite different from each other in terms of their income levels and hence the health care models adopted. The empirical analyses include several indicators of health expenditures by the source of financing, from private to external health expenditures, to simultaneously consider the effects of different financing sources on income growth (not levels) and the convergence process. In addition, the income tax rate as a fiscal policy variable implied by the theoretical models and the human capital index and openness to trade as control variables are also included in the analyses. The empirical findings provide support for absolute and faster conditional income convergence among OECD members while indicating evidence of absolute and faster conditional income divergence among LDCs. Furthermore, the findings indicate that private contributions, including those of households, corporations, and non-profit organizations, were doing well over the 20-year period in the OECD group. However, the results from LDC data show that health expenditures from all financing sources have a negative effect on long-run income growth, while only out-of-pocket health expenditures contribute to income growth and the convergence process. By combining theory and practice, this chapter also produces serious policy implications for both country groups.

Chapter 2 builds on the related literature in the following ways: The theoretical work in this chapter differs from previous studies that used a similar extended framework of neoclassical growth theory. In this regard, the theoretical study first fills a significant gap in the related literature by clearly distinguishing between consumption of health and non-health goods and services. Second, the models of the chapter simultaneously include both personal and public health spending in the felicity function instead of the level of health as in previous studies. Third, the externality in the models is generated differently by the means of health care expenditures spent from different sources. Another distinct feature of the approach used in this study is that the theoretical work in this chapter explicitly and endogenously considers the composition of public health spending. Although a few studies in the literature theoretically consider the role of public health spending, only a few of them address its endogenous composition. Each theoretical model developed in the chapter also contributes to the

literature by providing an answer to the question of what determines the consumption expenditures of individuals and the government devoted to health care.

To my best knowledge, there is also no study in the related literature that explicitly models both personal and public health expenditures by using an extended Solovian framework. Earlier studies that used the same framework all focused on the stock of health in their theoretical parts instead of on the flow of health expenditures. Therefore, these two augmented Solow models developed in this chapter provide a new theoretical background to formally test income convergence conditional on the shares of personal and public health expenditures. Moreover, in each model, both personal and public health expenditures are endogenously defined as constant shares of output. On the upshot, the work in this chapter fills an important gap in the related literature and represents the first attempt at formally inquiring into the link between health spending and growth by considering the financing agent of this spending. Lastly, the empirical research of the chapter departs from previous empirical studies by (i) employing a dynamic panel data approach with its superior features, (ii) using several indicators of health spending regarding different financing sources instead of total health expenditures used by previous studies, and (iii) including two quite different country groups in the analyses to compare and discuss their differences on this nexus with more recent data.

Finally, under the title *“A Driver for Health Decay: No Theory Just Evidence”*, Chapter 3 examines the link between per capita income growth and poor weight-related health, proxied by adult obesity, which is one of the main causes of a decay in good health status and high rates of discount in health capital. Different from the first two chapters, this chapter relies on a Barro-regression approach and dedicates itself to an empirical neoclassical growth framework. To this end, two separate empirical models are employed in the study. Chapter 3 first tests the hypothesis of obesity convergence among 38 OECD members and simultaneously investigates the economic determinants of the growth in adult obesity rates. Then, the chapter examines the impact of adult obesity and its determinants, including real income per capita, income inequality, unemployment, and trade openness, on income growth and the convergence process in addition to traditional determinants of income convergence such as the savings rate, the population growth rate, and the human capital index.

The findings of the study provide clear evidence of absolute and faster conditional obesity convergence among the members of the OECD over the 42-year period. The main results of the study further suggest that economic factors significantly explain the observed trends in obesity prevalence to an extent that should not be ignored among other non-economic determinants, including genetics, health conditions, and medications. Moreover, the results significantly indicate that more unequal societies within the OECD are more vulnerable to being obese, and more openness to trade is correlated with better weight-related health through its health-promoting effects, *i.e.*, easy access to different kinds of medical supplies and good health practices. As a result, examining the nexus between income growth and obesity, which is one of the most serious public health challenges around the globe and particularly in the OECD region over the last four decades, reveals important information for institutions and policy-makers to develop common preventive policies on this issue.

The study in Chapter 3 also significantly contributes to the related literature in several respects. In the related literature, there are only a limited number of macro-level studies that investigate the hypotheses of absolute and conditional β -convergence in obesity among OECD members. To my best knowledge, only the studies of Duncan and Toledo (2018a, 2018b) have simultaneously analyzed absolute and conditional β -convergence in obesity among European Union (EU) members by employing traditional cross-sectional tests. Hence, compared to previous studies, the study in this chapter contributes to the limited and related literature by examining both absolute and conditional β -convergence in adult obesity in all 38 members of the OECD. Furthermore, different from the above studies, this study investigates the determinants of obesity growth from a macro-level perspective by including real income per capita, Gini coefficients, the total unemployment rate, and openness to trade in the analyses.

This chapter further contributes to the related literature by examining the impact of adult obesity on income growth and the convergence process. To my best knowledge, there are only two macro-level studies in the literature that have empirically examined this nexus for the states of the U.S. (Alexiadis and Eleftheriou, 2011) and for transition economies (Osmonbaeva, 2021) by using traditional Ordinary Least Squares (OLS) and Autoregressive Distributed Lag (ARDL) approaches,

respectively. Therefore, from a macro perspective, this study further fills the gap in the related literature by examining the effects of adult obesity and its determinants on income growth and convergence among 38 OECD members. Moreover, in each analysis, the study employs a more robust and dynamic panel data approach compared to previous studies, which seriously suffer from heterogeneity and endogeneity bias.

The plan of the thesis is as follows: Chapter 1 first introduces the motivation of the study and then gives an extensive literature review on the studies that examine the growth effects of health status in a neoclassical growth framework. Section 3 of the chapter explains the theoretical model, gives long-run solutions, and derives a testable output convergence equation. Section 4 represents the empirical part of the study and includes three subsections. The first subsection describes the empirical methodology of the study by discussing panel unit root tests (PURT) used prior to the analyses, and then explains in detail the methodological approach used in the study. The second subsection presents the data, and the third subsection gives the empirical findings of the study. Finally, the last section discusses its policy implications.

Chapter 2 first explains the main motivation of the study and provides a literature review on the related studies that examined the relationship between health expenditures and economic growth in the second section. Section 3 deals with two augmented Ramsey models, explains their long-run solutions, and provides a few extensions to the models for comparison purposes. The related appendices contain the social planner solutions for each model. Section 4 further develops two augmented Solow models, presents their long-run solutions, and derives two income convergence equations. Section 5 covers the empirical part of the chapter and explains the methodology, the sample data, and the empirical findings of the study. Finally, Section 6 concludes the chapter and provides some policy implications.

Lastly, Chapter 3 reviews previous studies on the determinants of obesity, obesity convergence, and the link between obesity and income growth after providing some recent facts on the obesity epidemic in Section 1. Then, Section 3 describes the two empirical models to be estimated in the study and clearly explains the main arguments of the empirical models. Section 4 presents the methodology, the data, and the empirical findings of the study. Section 5 concludes the chapter and discusses its policy implications.

CHAPTER ONE

IN SICKNESS AND IN HEALTH: SOME THEORY MORE EVIDENCE

“All theory depends on assumptions which are not quite true. That is what makes it theory. The art of successful theorizing is to make the inevitable simplifying assumptions in such a way that the final results are not very sensitive.”

Solow (1956: 65)

1.1. INTRODUCTION

Health changes the course of economic growth through a number of conceivable pathways. As an essential element of human capital, investments in health directly support the formation of human capital, and better health status directly increases the supply of human capital (Van Zon and Muysken, 2001). As a prerequisite for producing other components, including education, skills, experience, and learning, improvements in health status indirectly enhance the quantity and quality of human capital. It allows and induces the further generation of education, learning, and skill-building activities and increases the returns on investments in other forms of human capital (Becker, 2007; Behrman, 1996; Bleakley, 2010; Leslie and Jamison, 1990).

Furthermore, improvements in health status indirectly trigger the investments in physical capital available to an economy by raising the rate of savings, given the argument that better health outcomes induce individuals to save more for retirement (Bloom *et al.*, 2003; Lee *et al.*, 2000). The changes in health status also affect the demographic characteristics of a country via the changes in the rate of population growth, the age structure of the country's population, and hence the dependency ratios (Bloom and Canning, 2000). In this sense, several studies have shown that higher longevity leads to reduced population growth, lower fertility rates, and further accumulation of human capital, especially in post-transitional high-income countries (Desbordes, 2011; Hansen and Lönstrup, 2015; Soares, 2005).

In this way, health affects the production process itself via its effects on the production inputs or on the parameters involved in the accumulation process of these inputs. However, the first and foremost impact of health is directly on a country's labor input. Improvements enhancing the healthiness of a country's workforce boost productivity and, hence, the pace of economic growth through their positive effects on

the quantity and quality of the labor force. Good health directly increases the labor force participation rate in a country, decreases the number of illness-related absent days from work, and enhances workers' effort and productivity. In this sense, micro-level evidence has indicated that the level of ill-health affects the amount of labor supplied to an economy (Grossman, 1972a, 1972b) and that improved health status directly affects labor productivity positively (Becker, 1962; Mushkin, 1962; Schultz W., 1961; Schultz P., 2002; Strauss and Thomas, 1998).

For instance, Stewart *et al.* (2003) have found that the burden of poor health-related productivity losses, which include reduced performance at work (presenteeism) and work absence (sickness absenteeism), is substantially higher and costs about \$1,685 or more per American employee per year (Stewart *et al.*, 2003: 1241). Grinza and Rycx (2018) have further shown that a 1% increase in the rate of work absenteeism due to illness is associated with about a 0.24% decrease in productivity, arguing that absenteeism has a considerable negative impact on productivity. In this context, sickness absence due to poor health is one of the principal reasons for lost productivity in the production process, which significantly results in a decrease in output per worker, especially if there is no perfect substitute for the absent labor (Pauly *et al.*, 2002; Tompa, 2002). Therefore, besides its direct medical costs, the poor health of a country's workforce incurs higher indirect costs in terms of absenteeism, reduced productivity, and hence lower long-run output growth.

In line with microstudies, the macro-level evidence has shown that good health significantly enhances worker productivity and long-run economic growth. Early studies in this field have analyzed historical trends and shown that during the past few centuries, improvements in health status through improvements in height, weight, and nutrition have contributed to an increase in the levels of worker productivity and per capita income across Europe and America (Costa and Steckel, 1995; Floud, 1984; Fogel, 1990, 1994; Steckel, 1995). On the other hand, after neglecting it for a long time, the growth literature has also recognized health as one of the main components of human capital, along with education, and revealed that health is a robust predictor of long-run economic growth.

In this context, Knowles and Owen (1995) were the first in the related literature to draw attention to the health component of human capital by further augmenting the

Solow (1956) model with a health capital accumulation function, following the seminal contribution of Mankiw *et al.* (1992). Subsequently, there have been other theoretical efforts to incorporate health human capital into the growth modeling. For instance, in an extended neoclassical framework, Barro (1996b) and Muysken *et al.* (1999) have examined the interaction between health and economic growth and concluded that health directly raises economic growth and the productivity of the labor force. In an endogenous growth framework à la Lucas (1988), Van Zon and Muysken (2001, 2003) have studied the notion that health as human capital is an important determinant of long-run economic growth. Furthermore, in a Schumpeterian growth framework, the studies of Howitt (2005) and Madsen (2012) have been among other significant theoretical contributions, indicating that good health positively affects long-run growth.

However, the studies examining the growth-health nexus have mostly centered around the neoclassical framework, which still provides a basic and appropriate outline to study the drivers of growth and the real income differences across countries. These studies have aimed to explore the growth effects of health capital and have contributed to one of the main ongoing debates in modern growth literature for more than a half-century, *i.e.*, the debate of convergence. One common conclusion from this type of research has been the evidence of health as being one of the most significant drivers of long-run economic growth and its vital role in explaining per capita income differences across countries. The studies subject to this framework are roughly divided into two clusters. Following the pioneering contribution of Knowles and Owen (1995), the first group includes a relatively limited number of studies that have exploited the canonical Solow model and estimated a theory-backed convergence equation to examine the growth effects of health capital (Heshmati, 2001; Knowles and Owen, 1997; McDonald and Roberts, 2002; Rivera and Currais, 1999a, 1999b; Webber, 2002).

The latter group consists of growth studies that are purely empirical and have made use of the Barro-regression approach to informally incorporate health into growth regressions testing the neoclassical argument of convergence. This approach, which has been primarily led by Barro (1991), has been adapted by a large number of studies that include initial income and proxies of health in their cross-country

regressions along with additional possible determinants of growth (Barro, 1996a; Barro and Lee, 1993, 1994; Bhargava *et al.*, 2001; Bloom *et al.*, 1998; Gyimah-Brempong and Wilson, 2004). Although these studies have roughly employed the same empirical equation due to its origin, they all suffer from a lack of formal theoretical derivation and, hence, from obtaining a clear theoretical link between growth and health, which makes it difficult to properly explain the growth impacts of the coefficients of interest (Bloom *et al.*, 2004; Temple, 1999).

In this context, this chapter aims to explore the effects of a healthy labor force on long-run economic growth and the convergence process in a narrowed Solovian framework, which is narrowed in the sense that it employs only healthy workers in a country. Hence, deviating from related literature, the main concern of the study is to provide a theory-backed convergence equation that highlights the difference between healthy and unhealthy workers that are absent from work due to ill health. The details of the study are as follows: The theoretical part of the study assumes that a country's production function sensibly includes only healthy workers at any instant of time by emphasizing the role of sickness absence in the production process. Thus, from a macro perspective, this study addresses workforce absenteeism due to ill health, which has been examined only in a few micro-based studies before. The study provides the steady-state solutions of the derived model and develops a convergence equation conditional on the rate of savings, the rate of workforce growth, and the share of healthy workers in the total workforce.

The study further extends the above model by assuming the existence of a generous government, whose expenditures are endogenously covered by income taxes and have a positive externality effect on the whole production process of the firms. Following these, the empirical part of the study provides system GMM estimates to examine the implications of a healthy labor force on growth and the convergence process among OECD countries. In this sense, the share of healthy working hours in total working hours is used as a proxy for a healthy workforce, and age-specific measures of life expectancy and adult mortality between ages 15 and 60 are used as proxies for the health status of the working-age population in the empirical analyses.⁷

⁷ Although the working-age population is referred to as those aged 15 to 64, the health status indicators cover the ages 15-60 due to data availability.

The estimations further include fiscal policy variables in line with the extended theoretical model and also control variables, including human capital in the form of education and openness to trade.

The research in this chapter significantly contributes to related literature that particularly focuses on the growth and convergence impacts of health in a neoclassical framework. From a theoretical standpoint, first, this study significantly departs from the empirical studies lacking a formal theoretical derivation by providing a clear link between the theory and empirics of growth. Second, by directly focusing on the absenteeism implications of poor health, this study further deviates from the related studies that were pioneered by Knowles and Owen (1995) and have used a theory-based approach. In this sense, previous studies, though exploiting the well-established Solow framework, all mimic the same health human capital accumulation equation in their theoretical parts. However, this study diverges from this common specification of health capital, which has been mostly used as a separate input or labor-augmenting factor in the production process.

Hence, the study clearly defines healthiness over a country's total workforce by giving particular attention to sickness absence. To my best knowledge, there is only one study in the related literature that examines the growth implications of health through its labor-supply implications. In this sense, Muysken *et al.* (1999) were the first to have theoretically examined the trade-off between optimal health expenditures, consumption, and physical capital by adding a healthy workers' accumulation function into the Ramsey (1928) growth model. Building on a similar spirit, but unlike Muysken *et al.* (1999), this study focuses on the growth and convergence effects of a healthy labor force by using a Solovian setup with the government and empirically tests the derived output convergence equation.

From an empirical perspective, third, the study differs from other studies by means of the methodology employed. This study employs a dynamic panel data estimator, the system GMM, to eliminate the shortcomings of the methodological approaches used in previous studies. Earlier studies in the mainstream literature extensively used cross-sectional and pooled or dubious dynamic panel data techniques to estimate their theory-backed convergence equation, which are not suitable for the dynamic nature of the convergence specification. These previous approaches suffered

from limited time variation in the growth variables, the omission of the unobservable factors that include the evolution and level of technology, and other unknown growth-related factors, the issue of endogeneity, finite sample bias, and the weak instrument problem. However, in terms of growth empiricism, the system GMM estimator allows (i) to control for common temporal differences in technological change across countries, (ii) to include the differences in the level of technology and in other growth-related factors, (iii) to deal with a potential endogeneity arising from measurement errors and simultaneity between growth variables, and (iv) to enhance precision for short panels and highly persistent series. Therefore, the methodology used in this study ensures the obtainment of more precise and unbiased estimates of the coefficients on Solow-convergence variables compared to those that have been employed in the earlier studies (Bond *et al.*, 2001).

Fourth, this study employs a few health indicators specific to the working population of a country that are different from those that have been used in previous studies. Most of the related works in the literature have typically used two crude measures of health: life expectancy at birth and infant or child mortality, though they have aimed to examine the productivity implications of health. However, these indicators capture the health level of the entire population, including the dependent population, and are not appropriate to consider the effects of health on per-worker growth variables (Arora, 2001; Jamison *et al.*, 2005). Thus, this study uses the share of healthy working hours per worker as a proxy for the share of healthy workers in the total workforce. Hence, the study completely excludes unhealthy workers from the production process as they are absent from work due to ill health.

To this end, to the best knowledge of the author, this study is the first in related literature that uses aggregate data on health-related absence from work. The study further employs two additional indicators to proxy for the health status of the most productive age span in a country: life expectancy at specific ages from 15 to 60 and the adult mortality rate between ages 15 and 60. Fifth, studying the growth-health relationship within the scope of OECD countries provides a significant contribution to the related literature, as most previous studies have focused on low-income countries or a broader range of countries. In particular, for high-income countries, the evidence is still limited and controversial. Hence, as stated by Tompa (2002), more research is

required to investigate the productivity-effects of health in order to develop better policy responses, particularly in developed countries, *e.g.*, by employing health proxies that are more appropriate for this country group, such as measures of functional status (Tomba, 2002: 190-197). Lastly, compared to other studies, this study uses more recent data over a relatively long period of time to properly explore the impacts of health on the out-of-steady-state dynamics of per-worker output.

The main results of the study are as follows: The theoretical results show that the steady-state values of the per-worker Solow variables are all lower than those obtained from the solution of the standard Solow model, which assumes all workers are always in good health status. In other words, an increase in the number of health-related absent days leads to a significant decrease in long-run productivity and per-worker values of physical capital and consumption. Furthermore, the theoretical results show that increases in the share of healthy workers raise not only per-worker output but also per-worker government expenditures, which are met by a constant share of output as income taxes. However, the theoretical findings further indicate that, at long-run equilibrium, all per-worker variables of the model still grow at the rate of technological progress.

The empirical findings based on system GMM estimates show that increases in the share of healthy workers have a positive and sizeable effect on output convergence and long-run growth in OECD countries, confirming the theoretical results of the study. In other words, the findings significantly imply that sickness absenteeism incurs higher costs for OECD countries in terms of reduced productivity, lower savings, and hence lower long-run output growth. Similarly, the results show that the good health status of the workforce, in terms of increases in young- and middle-age longevity and decreases in adult mortality between ages 15 and 60, has a positive and significant impact on long-run output growth. Furthermore, the improvements in the health status of the working-age population remarkably help to eliminate output differences among OECD members.

In more detail, first, the empirical findings of the study show that the inclusion of all health proxy measures significantly increases the speed of convergence among OECD countries. In this sense, the estimated rates of convergence are robust to the inclusion of fiscal policy and control variables, as the findings show that OECD

members converge at a rate of about 6% per year if the estimations consider the share of (un)healthy workers. On the other hand, secondarily, increases in young-age longevity significantly produce higher increases in the rates of output growth and convergence compared to other working-age groups. However, the estimated convergence rates gradually decrease with increasing age. In this context, the results indicate that annual gains in life expectancy at ages 50 and 60 have an insignificant effect on output growth and convergence.

Third, in parallel to the above findings, the inclusion of health proxies—the share of healthy workers and life expectancy at younger ages between 15 and 30—leads to higher estimated output shares of labor in the estimations. In this sense, lower capital shares result in a quick setting of diminishing returns, as assumed by the Solow model, which in turn significantly explains the faster convergence rates of OECD countries obtained in the estimations. Following that, the estimations controlling for the longevity of ages 40, 50, and 60 produce a relatively higher weight for physical capital. In this sense, given the aging of the workforce in OECD countries (OECD, 2019b, 2020a), the findings of this study seriously imply that the health status of the workers who approach the end of their working lives and retirement, will seem to become an even more important issue in the near future.⁸

Fourth, although the savings rate has a positive and highly significant effect on growth in all regressions, the growth effects of savings decrease with the inclusion of a healthy share of workers in the analyses, whose number is always less than the total number of workers available in practice. On the other hand, the growth-enhancing effects of savings increase dramatically as working age increases. Hence, this finding reflects the fact that (i) longevity leads individuals to have greater incentives to save for older ages and (ii) increases in longevity at ages 50 and 60 increase output growth indirectly through increases in savings, as the highest estimated savings rates are obtained in the regressions of these age groups. Fifth, the findings of the study further indicate that the rise in adult mortality significantly lowers long-run growth of output,

⁸ In 2019, the total employment rate of people aged 55-64 in OECD countries was 62.1% of the total number of people in that same age group (OECD, 2022a). Furthermore, compared to other age groups, the working population at age 65 and older is highest in 38 OECD countries, with an average of about 5546 thousand people over the years 2010-2021 (ILOSTAT, 2021b).

the growth-promoting effects of savings, and the negative effects of workforce growth across OECD countries.

Six, the results of the study also contribute to the ongoing debate on the growth effects of education and health and show that good health is a stronger determinant of output growth than education, as human capital in the form of education is insignificant in all regressions. However, the findings imply that controlling for educational human capital changes the growth effects of health proxies differently due to the diverse natures of the two health indicators, *i.e.*, the healthy share of workers represents more morbidity, whereas life expectancy refers more broadly to the quality of human capital (Barro, 1996a). Lastly, openness to trade, the income tax rate, and the share of tax revenue in GDP have insignificant roles in explaining output growth among OECD countries, but the share of government spending has a significantly negative impact on growth, reflecting the large budget deficits of OECD countries in the sample period (OECD, 2015).

The research in this chapter provides valuable insights into the critical role that policy can play in promoting workforce health, ultimately productivity, and long-run output growth. Given the results that good health status is a significant measure of productivity and of the gap in real output differences, policy-makers in OECD countries need to be aware that a country's ability to remain productive depends on the quantity and quality of its workforce and the years for which labour remains productive, which in turn primarily and vitally depends on health. Moreover, the findings seriously imply that improvements in the health status of the younger workforce through health investments and encouraging the savings of the older workforce through a more efficient investment environment will significantly enhance the long-run output growth of OECD countries. Finally, in these days during the COVID-19 pandemic, in which the links between health status and economic productivity have become a more significant policy concern, the results of the study have further implications for OECD economies.

Total worked hours decreased by more than 15% in the second quarter of 2020, according to the OECD (2021), and worked hours in March 2021 were still 7% lower than in 2019 across OECD countries (OECD, 2021: 19). The reduction in total working hours resulted from the decrease in the number of workers and the decrease in the

weekly working hours of workers still at work (ILO-OECD, 2020). Furthermore, the pandemic results in serious losses in the stock of the workforce and damages the physical and mental health status of the workers in all countries. Particularly, the pandemic results in life expectancy at birth falling in 24 of the 30 OECD countries in 2020 (OECD, 2021: 80). Additionally, according to the report of the OECD (2021), there were more than 1.8 million excess deaths in 2020 than those observed in the previous five-year period, and the number of deaths is expected to increase by about 16% in 2020 and in the first half of 2021 across OECD countries (OECD, 2021: 84). Hence, given the findings of this study, policy-makers in these countries may need to urgently take serious measures, a mix of health and economic policy interventions, to recover working-hour losses and enhance the health status of the existing labor force through investments in health in order to counteract the adverse effects of the pandemic on future productivity and economic growth.

The organization of the chapter is as follows: Section 2 represents a comprehensive review of the related studies, in which the discussion on the growth effects of health is directly focused on Solow-type regression models. Section 3 explains the theoretical model, gives solutions to the model, and derives a testable output convergence equation. Section 4 represents the empirical part of the study and includes three subsections. The first subsection describes the empirical methodology of the study by discussing PURTs applied before the analyses and then the methodological approach used in the study. The second one presents the data, and the third subsection gives the empirical findings of the study. Finally, Section 5 concludes the study and discusses its policy implications.

1.2. LITERATURE REVIEW

Originating from the studies of Solow (1956) and Swan (1956), one of the most appealing research areas revealed by neoclassical theory has been the convergence dynamics across countries. The pioneering models of neoclassical growth predicted that the rate of per capita income growth inversely relates only to the initial level of

per capita income, due to diminishing marginal returns to physical capital.⁹ This prediction refers to β -convergence¹⁰ hypothesis in an absolute sense, which has been the topic of intense controversy and has been rejected by the growth literature, primarily by the studies of De Long (1988) and Baumol and Wolff (1988). That is, if extended to include a group of countries, the growth literature has shown that only countries that have similar levels of population growth rate, savings propensity, access to technology, and policy variables can absolutely converge to a common steady-state level of per capita income in the long run. Hence, rather than absolutely, the neoclassical theories of growth predict that the per capita income levels of countries converge conditionally.

Hence, the conditional β -convergence hypothesis suggests that a country's growth rate depends on how far the initial level of per capita income is from its long-run equilibrium value controlled by other determinants of growth. In other words, when looking at a group of countries' economies, differences in growth rates can be attributed not only to differences in initial incomes but also to differences in steady-state income levels, which are determined by other fundamental parameters. In this sense, a large number of studies in the literature have revealed that the conditional convergence hypothesis applies to geographical units that are similar in the fundamental structural characteristics, including technology, population growth, preferences, government policies, etc., which shape the long-run equilibrium values of their per capita incomes (Barro and Sala-i-Martin, 1990, 1992b; Sala-i-Martin, 1996a, 1996b).

In this context, human capital is one of the important characteristics that shape the long-run equilibrium value of the countries' per capita real incomes. Primarily, the importance of human capital in economic growth has been emphasized by several pioneering studies in literature (Arrow, 1962; Lucas, 1988; Nelson and Phelps, 1966;

⁹ It is actually known that the key proposition of the neoclassical growth model is convergence within a country rather than convergence across countries, but the concept has evolved over time and been extended to a cross-country concept and was intensively studied in this framework.

¹⁰ This chapter focuses only on the concepts of absolute and conditional β -convergence. In other words, the chapter includes the studies employing the concept of β -convergence in a cross-country setting by using the growth or initial level of income per capita or worker and health proxies as dependent and explanatory variables, respectively. As a result, studies focusing on the distributional properties of per capita income, pure time-series studies, or the analysis of local convergence are excluded from this chapter's review.

Rebelo, 1991; Romer, 1986, 1990; Schultz, 1960; Uzawa, 1965). Subsequently, based on the seminal contributions of Barro (1991) and particularly Mankiw *et al.* (1992), the concept began to be studied within the scope of the income convergence argument as being among the major attributes that explain the long-run growth of countries. In this sense, Barro (1991) has developed an *ad hoc* regression approach to empirically test the conditional income convergence hypothesis by including human capital among the other determinants of per capita income growth.^{11,12} In his study, Barro (1991) used school enrollment rates as a proxy for human capital and stated that, for a given initial value of per capita income, poor countries tend to grow faster than rich ones, but only if the poor countries' human capital exceeds the amount that accompanies their low level of per capita real income (Barro, 1991: 409).

Mankiw *et al.* (1992), on the other hand, were the first to provide a formal theoretical framework for empirical income-convergence testing. In their study, they have developed an augmented Solow model that includes both physical and human capital stocks as production inputs and derived an income convergence equation conditional on the accumulation amounts of these inputs. In the empirical part of their study, they have demonstrated that real per capita income levels conditionally converge among countries with similar levels of technology and stocks of physical and human capital by using secondary-education enrollment rates as a proxy for human capital. Thus, human capital has taken its place in the convergence regressions as one of the important structural characteristics that explain the differences in per capita real incomes of the countries, or, in the same sense, that control the similarities among the countries. Since then, a vast body of literature has emerged on conditional convergence once the standard neoclassical framework is extended to include human capital following these seminal contributions (Barro and Sala-i-Martin, 1992a; Benhabib and Spiegel, 1992, 1994; Cohen, 1996; Ding and Knight, 2009; Evans and Karras, 1996;

¹¹ After the study of Barro (1991), these growth regressions, also known as Barro-type regressions or the Barro-regression approach, have been intensively used in empirical growth studies. These regression models are estimated to examine the alternative determinants of growth and to test the conditional income convergence hypothesis by adding different independent variables explaining the growth rate of per capita income to the RHS of the growth regression equation along with the initial level of per capita income. For a detailed description, please refer to Barro and Sala-i-Martin (2004) and Eq. (18) in Durlauf *et al.* (2005): 580-581.

¹² There have been other initial efforts before Barro (1991) that are similar in spirit, such as Robinson (1971), Kormendi and Meguire (1985), and Grier and Tullock (1989).

Hoeffler, 2002; Islam, 1995; Knight *et al.*, 1993; Levine and Renelt, 1992; O'Neill, 1995). The findings of these studies have revealed evidence for the existence of conditional convergence among structurally similar countries and emphasized the significant role of human capital in the form of education in explaining income differences across countries.

Much of the early work on convergence research has centered around human capital in the form of education by using schooling or enrollment ratios. However, the notion of human capital broadly refers to the attributes of a country's human resources, by means of which that country is able to boost its productivity and economic growth. These attributes include the knowledge, experience, and skills that individuals invest in and accumulate to increase their productivity, but also good health as a priority that allows for an increase in the number of human resources in a country and complements other attributes to have better outcomes and increase their returns. Hence, despite being one of the main components of and a complement to human capital (Becker, 1962; Mushkin, 1962; Schultz, 1961, 1962), health was largely ignored in the early discourses of growth studies. In this respect, Knowles and Owen (1995, 1997) were the first to include and attract interest to the missing component of human capital in a neoclassical growth framework by augmenting the canonical Solow model.¹³ Ever since, the role of health in explaining cross-country income differences and growth has become a serious focus of growth inquiry.

Knowles and Owen (1995) have further expanded the augmented Solow model proposed by Mankiw *et al.* (1992) by including health and education as separate production inputs and examined their effects on income growth for a cross-section of 84 non-oil countries over the 1960-1985 period. Thus, they have proposed a formal, theory-backed growth regression to empirically examine the growth implications of population health. Their results have indicated that longevity at birth as a proxy for health capital has a positive and significant effect on growth for 62 LDCs, but its effect

¹³ There were also other initial efforts to incorporate health into a standard neoclassical growth framework. For instance, Cuddington (1993) and Cuddington *et al.* (1994) have used the Solow model by adding an epidemic equation to explore the long-run effects of AIDS on economic growth. Their findings have shown that AIDS-related morbidity and mortality decrease the size of the labor force, their productivity, and hence the growth performance of countries. However, these studies have focused on a disease-specific definition of health rather than its broad definition as in Knowles and Owen (1995, 1997).

is insignificant for 22 high-income countries. Their findings have further shown that health has a more robust effect on the growth of per-worker income compared to education, as the coefficient on educational capital is insignificant in all regressions that simultaneously include health capital. In another study, Knowles and Owen (1997) treated health and education as labor-augmenting factors instead of production inputs and reported similar results for a sample of 77 countries during the same period of 1960-1985. Their findings have shown that the effect of life expectancy on income growth is significantly positive for 55 LDCs but insignificant for 22 high-income countries. They have also reported that the relationship between per-worker income growth and education is still insignificant in all estimations, even if health proxies are inappropriately removed from the regressions.

Following Knowles and Owen (1995, 1997), several studies on growth have augmented the Solow model with health capital to assess its impact on the cross-country income convergence process. For instance, Rivera and Currais (1999a, 1999b) and Heshmati (2001) have reported a positive and significant effect of health, proxied by health expenditures, on per-worker income growth across OECD countries over the periods of 1960-1990 and 1970-1992, respectively. Similar to the results of Knowles and Owen (1995, 1997), McDonald and Roberts (2002) have found that the coefficients of health variables proxied by life expectancy at birth and infant mortality are significant for LDCs but insignificant for OECD countries over the 1960-1989 period. Webber (2002) has further found that undernutrition measured in terms of the caloric intake per capita has no role in explaining income differences for a cross-section of 46 countries over the 1960-1990 period. More recently, Li and Huang (2009) have also tested the income convergence hypothesis for the 1978-2005 period across the provinces of China. By using new proxies for health, such as the number of hospital beds and doctors per 10,000 people, their findings have shown that health has a positive and significant effect on economic growth.

On the other hand, all these studies employing a theory-backed convergence regression have also included education as another component of human capital in their analyses, similar to Knowles and Owen (1995, 1997). However, their results on the growth effects of education are erratic. A few of them have shown that the effect of education is significant and positive for high-income OECD countries (Rivera and

Currais, 1999a, 1999b; McDonald and Roberts, 2002); for a cross-section of large countries (Webber, 2002); and for the provinces of China (Li and Huang, 2009), while others have reported insignificant effects for OECD members (Heshmati, 2001; Knowles and Owen, 1995, 1997). Furthermore, Knowles and Owen (1995, 1997) and McDonald and Roberts (2002) have indicated that the coefficient on educational capital is insignificant for the sample of low-income countries. On the other hand, Webber (2002) and Li and Huang (2009) have found that education has a more significant effect on economic growth than health. In this sense, they have also argued that policies to promote economic growth should favor investments in education over health. However, if one considers the mutual relationship between health and education such that more educated (healthy) people are healthier (better educated) (Becker, 2007; Groot and Van den Brink, 2007; Grossman, 1999), the results of these studies may suffer from a high collinearity problem that results in biased estimates of the coefficients on both variables. In this sense, Arora (2001) has also stated that it is nearly impossible to use both variables simultaneously in a single regression due to high collinearity between the two, which makes it difficult to disentangle properly the effects of either variable on growth (Arora, 2001: 723-724), particularly with the methodologies used in their analyses.

Another common approach in the literature for explaining the path from health to income growth has been the use of *ad hoc* regressions, following Barro (1991). In this context, an enormous body of research has used the Barro-regression approach to examine the relationship between health status and economic growth in a cross-country framework. The primary goal of these studies has been to determine whether countries' income levels will converge in the long run based on structural growth parameters and variables such as health, among others. As a result, these studies have broadened convergence equations to include any variable thought to be related to income growth, such as health, educational attainment, fertility, and economic policy, while simultaneously incorporating initial income levels into the right-hand side (RHS) of growth regressions to account for transitional dynamics. Most have confirmed that health measured by longevity at birth, adult survival rates (ASRs), and mortality rates is significantly related to economic growth and the convergence

process, and most of them have concluded that better health predicts higher economic growth.

In this sense, Barro and Lee (1993, 1994) have examined the linkages between fertility, infant mortality, and longevity and shown that improvements in health measures significantly enhance economic growth. According to their results, increases in longevity at birth raised economic growth by about 1.5% per year over the 1965-1975 period. Their findings have further indicated that there is a quadratic relationship in the sense that the impact of life expectancy on fertility is positive at lower levels but becomes negative after a threshold of 46 years. According to their results, the same is true for lower levels of infant mortality, implying that higher mortality results in lower fertility after a certain point. They have further argued that the effect of education is less important than health, and health is a stronger predictor of subsequent income growth than education. In another study, Barro (1996a) has also found that higher starting levels of longevity and male schooling, lower fertility rates, and improvements in terms of trade are all significant predictors of economic growth. On the other hand, Caselli *et al.* (1996) re-examined standard growth regressions using a different methodology, the difference GMM. In their study, using the same sample as Barro and Lee (1993), they found a negative and insignificant coefficient for life expectancy at birth and argued that the cross-sectional approaches suffer from significant inconsistency problems that frustrate the findings of previous methodologies.

A few studies applying the same approach as Barro (1991) have examined the growth effects of health by focusing on a specific disease while controlling for initial income levels, tropical location, economic policies, and other population health outcomes. For instance, Ainsworth and Over (1994) have concluded that the HIV/AIDS epidemic decreases per capita income by about 0.33% in African countries. Furthermore, Hamoudi and Sachs (1999), Gallup *et al.* (1999), and Gallup and Sachs (2000) have all shown that the countries that are more vulnerable to malaria grow less, even when controlling for the improvements in longevity. In particular, Hamoudi and Sachs (1999) have found that malaria prevalence lowers life expectancy at birth by about 8%. Their findings also show that reducing infant mortality by two deaths per thousand live births raises income growth by about 1% over a 25-year period. Gallup

and Sachs (2000) have found that a 10% decrease in malaria prevalence is associated with about a 0.3% increase in income growth during the 1965-1990 period.

In alternative empirical models, determinants such as demographic and geographical features have been deemed as important factors in explaining the growth processes of the countries, in addition to initial income and population health. Some of these studies have shown that low initial life expectancy at birth is a strong predictor of slow economic growth in African and Asian countries over the 1965-1990 period (Bloom *et al.*, 1998, 1999; Bloom and Williamson, 1998). In this sense, Sachs and Warner (1997) have found that the effect of life expectancy on growth is greater at the lower levels of life expectancy, but this effect is almost zero at the higher levels, such as 70 years in the U.S. and France. On the other hand, Bloom *et al.* (1998) found that a 1% increase in initial longevity in 1965 raised income growth by about 3% per year. In terms of demographic changes, these studies have argued that improvements in health status due to increased longevity and reduced fertility enhance economic growth and lead to a more productive labor force, higher returns to investments in human capital in the form of schooling, and higher levels of savings. Hence, the resulting economic growth further leads to increases in longevity and reductions in fertility through lower dependency ratios and higher savings rates, which in turn cause another wave of economic growth among African and Asian countries.

These studies have further argued that geographical features such as the size of a country's land area in the tropics and a country's proximity to the disease environment and the equator have a significant role in explaining cross-country income patterns and economic growth. According to their findings, the HIV/AIDS epidemic and malaria tend to increase from temperate to tropical zones (Ainsworth and Over, 1994; Gallup *et al.*, 1999; Gallup and Sachs, 2000; Hamoudi and Sachs, 1999). Furthermore, their results have shown that tropical locations significantly reduce the income growth and health level of the population (Bloom *et al.*, 1998, 1999; Bloom and Williamson, 1998; Sachs and Warner, 1997). In this respect, Sachs and Warner (1997) have found that the growth rate of tropical countries is about 0.85% lower than the growth rate of non-tropical countries. Their estimates have further indicated that a 10-degree Celsius increase in average temperature per year decreases

life expectancy at birth by about 2.3 years, which in turn lowers savings and growth (Bloom *et al.*, 1998).

Some researchers following the same research tradition have argued that ASRs are a better proxy for population health in reflecting productivity and predicting economic growth rates. In this sense, Bhargava *et al.* (2001) used ASR to measure population health status for a panel of 92 countries between the years 1965 and 1990. Their results have shown that a 1% change in ASR is related to about a 0.05% increase in growth among low-income countries, but the effect of ASR becomes negative for developed countries such as the U.S., France, and Switzerland, which may be explained by the higher proportion of the elderly population in these countries. Following a slightly different methodological approach, Mayer (2001a) has shown that health, proxied by the probability of survival, significantly contributes to long-run income growth and that there exists a 30-year causality from health to income in 18 Latin American countries over the years 1950-1990. Mayer (2001b) has also demonstrated that health improvements among adults, as measured by lower adult mortality rates and a higher shortfall of life expectancy at birth from 80 years, resulted in significant long-term income increases in Mexican states between 1950 and 1995. Shastry and Weil (2003) have shown that the differences in anemia and ASR explain 1.3% and 19% of the variation in per capita income, respectively. Similarly, for a cross-section of 53 countries, Jamison *et al.* (2005) have shown that increases in the ASRs of males increased income growth by about 11% during the period 1965-1990. The findings of the studies have further shown that the proportion of a country's land area in the tropics is negatively associated with ASR (Bhargava *et al.*, 2001) and reduces growth rates by between 1% and 2% per annum (Jamison *et al.*, 2005).

Following a different production function approach, Bloom *et al.* (2004) have included health in an aggregate production function and shown that after controlling for work experience, a one-year increase in life expectancy at birth increases aggregate output by about 4% for 104 countries during the 1960-1990 period. In their study, they have further argued that the effect of life expectancy on growth regressions appears to be a real labor productivity effect. By employing the difference GMM estimator, Gyimah-Brempong and Wilson (2004) have examined the effects of health on per capita income growth among 21 sub-Saharan African (SSA) countries over the 1975-

1994 period and among 22 OECD countries over the 1961-1995 period. They have found that the coefficient of health measured by life expectancy at birth (infant mortality) is positive (negative) and significant. Their results have further indicated that the effects of health on growth are much larger in magnitude for African countries with relatively low levels of health capital compared to their effects for OECD countries. Chakraborty (2004) also found that longevity and starting income account for 42% of changes in growth across SSA countries over the 1970-1990 period and that countries with different amounts of health capital do not achieve the same living standards (Chakraborty, 2004: 121). Weil (2007) further found that reducing health differences as measured by ASR reduces variation in per-worker output by 10.6% across 42 countries. He has also argued that good health increases incentives and returns for more and better education at a given level of schooling and raises investments in physical capital.

Differently, Acemoglu and Johnson (2007) constructed a measure of predicted mortality and investigated whether health improvements since the 1940s had a significant effect on the growth performance of the countries. By using these predicted mortality rates as an instrument, they have found that longevity negatively affects both income per capita and output per worker. Hence, they have concluded that different factors other than those proposed by the neoclassical growth model may be needed to understand the impact of life expectancy on income levels. However, Bloom *et al.* (2014a) have criticized the results of Acemoglu and Johnson (2007) and shown that both levels and changes in health status have a positive role in income growth if initial life expectancy is properly included in the growth model.¹⁴ Eggoh *et al.* (2015) used the system GMM approach to examine the relationship between education, health, and economic growth in 49 African countries between 1996 and 2010. Their findings have shown that expenditures on education and health negatively affect economic growth, while longevity at birth, survival to age 65, and primary and secondary school enrollment rates have a positive effect. Their results have further indicated that investments in education and health are complementary for African countries in the sample.

¹⁴ Weil (2014) and Bloom *et al.* (2019) provide an excellent and recent survey of the studies that examine the health-growth nexus.

More recently, Madsen (2018) has found that improvements in health explain about one-third of the improvements in productivity among 21 OECD countries since 1865. By using similar methodology as in Eggoh *et al.* (2015), Sharma (2018) has found that longevity at birth and education have a positive and significant effect on the level and growth of real income for 17 developed countries over the years 1870-2013. By using difference GMM, Bane (2018) has further examined the impact of schooling and life expectancy at birth on income growth among low- and middle-income African countries over the period 1980-2015. According to their results, life expectancy at birth significantly explains the growth process of low-income African countries, but its coefficient is insignificant for middle-income African countries, while education has no significant effect on growth in either country group. Lastly, Bucci *et al.* (2019, 2021) have found that life expectancy at birth and education significantly explain the differences in long-run per capita incomes of OECD and non-OECD countries.

As a result, given the literature review above, there are roughly two main approaches to convergence studies: an *ad-hoc* regression approach, à la Barro (1991), and a theory-based approach following Mankiw *et al.* (1992). The first group models income growth over some specific periods of time as a function of initial conditions, human capital in the form of schooling and health, capital investments, policy variables, and demographic and geographical characteristics. Some stylized facts based on the findings of these studies are as follows: First, the data strongly support the pattern of conditional convergence given the initial levels of human capital, measures of government policy, and other characteristics. Second, nearly all of these studies have found evidence of a positive (negative) and significant influence of life expectancy at birth (infant mortality) and ASR on the subsequent pace of economic growth. Third, many of the existing studies have postulated a linear relationship between growth and health, while a few of them have found a nonlinear relationship such that good health status increases income growth at a decreasing rate after a certain level of income (Bhargava *et al.*, 2001; Gyimah-Brempong and Wilson, 2004; Sachs and Warner, 1997). Fourth, health status has other indirect effects on savings, education, and the demographic transition process of the countries via changes in fertility and mortality rates, in addition to its direct effects on labor productivity and

growth. Fifth, tropical regions mostly bear a heavy burden of disease and have poorer health outcomes than non-tropical ones.

On the other hand, these studies relying on *ad hoc* regressions have some limitations. For instance, as these regressions suffer from the lack of a clear link to the theory, in these studies, it is not specified whether health directly contributes to economic growth or is only a proxy for other missing factors related to income growth (Bloom *et al.*, 2004: 1). Furthermore, in these studies, it is not clear whether the variable that enters the regression specification affects income growth or the steady-state income level or both (Temple, 1999: 124). Therefore, it is usually not possible to distinguish between these two effects of the explanatory variables included in the informal regressions. However, the theory-based approach suggested by Mankiw *et al.* (1992) provides a simple and proper framework to study the variation both in income levels and in growth rates. Therefore, several studies in the literature have followed this more formal approach to study the role of health in explaining economic growth and cross-country income differences, as it can be legitimately used to obtain the estimates of the variables and parameters in the production function (Cohen, 1992, 1996; Temple, 1999), which is also the main interest of this chapter.

In this context, the studies that have relied on a theory-driven approach are all theoretically based on the augmented Solow model of output per worker. The findings of these studies have also strongly confirmed the existence of conditional income convergence, while their results on the effects of health are erratic. A few of them have shown that health has a positive and significant effect in least-developed and low-income countries (Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002), but the evidence in high-income countries has remained mixed. For the high-income context, some of them have reported an insignificant coefficient of health (Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002), while others have found a positive and significant effect (Heshmati, 2001; Rivera and Currais, 1999a, 1999b). Furthermore, by using a large cross-section of countries, Webber (2002) has found a positive but insignificant effect of health, while Li and Huang (2009) have reported a positive and significant coefficient for health status across Chinese provinces. Hence, although these studies have the same theoretical backgrounds, the heterogeneity

between their results mostly originates from their empirical parts, which differ in some crucial aspects and have some drawbacks as follows:

First of all, the specification of the dependent variable is different across the convergence regressions, *i.e.*, the treatment ranges from growth to the log level of income and gross product or from per worker to per capita income. The majority of studies used the growth rate of per-worker income as the dependent variable (Heshmati, 2001; Knowles and Owen, 1995, 1997; Rivera and Currais, 1999a, 1999b; Webber, 2002), while a few used the log level of per-capita or per-worker income (Li and Huang, 2009; McDonald and Roberts, 2002). Secondly, in their theoretical parts, these studies have used a common human capital accumulation function, which is further divided between the stocks of education and health capital to be used as inputs in production. Therefore, in each study, the steady-state approximation has been obtained by using the fractions of income invested in three forms of capital, which are assumed to have the same depreciation rates. In this sense, although the convergence equations of these studies include the fractions of income invested in two forms of human capital, in their estimations, most of them have used proxies that show the level of human capital instead of the rate of accumulation. In this sense, the studies of Rivera and Currais (1999a, 1999b) and Heshmati (2001) are the two exceptions, in which health expenditures are used to proxy for the share of income invested in health.¹⁵

Accordingly, and third, although most of these studies aim to explore the productivity implications of health through the labor force, they have proxied the health status with indicators such as life expectancy at birth and infant or child mortality rates (Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002), the caloric intake per capita (Webber, 2002), and the number of hospital beds and doctors (Li and Huang, 2009). Furthermore, a few of them have measured life expectancy as the shortfall of the average life expectancy at birth from 80 years (Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002). However, these indicators are not relevant

¹⁵ Mankiw *et al.* (1992) have argued that the choice of the specification of the convergence regression and of the related human capital measures should depend on the available data on human capital, *i.e.*, whether they correspond more closely to the rate of accumulation or to the level of human capital. However, it should be noted that these alternative specifications will predict different coefficients for savings and population growth (Mankiw *et al.*, 1992: 418). Please refer to Mankiw *et al.* (1992) for a discussion on the choice between the level of human capital versus the investment in human capital in the context of the Solow model.

for productivity measurement and reflect the health level of the population instead of the working-age population. Fourth, all of these studies have included schooling variables in their regressions to proxy for education as another component of human capital. A few of them have shown that the coefficient on educational capital is significant and positive (Li and Huang, 2009; Rivera and Currais, 1999a, 1999b; Webber, 2002), while others have reported insignificant coefficients (Heshmati, 2001; Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002). However, in most cases, it is hard to ascertain whether the robust growth effects are generated by health or schooling variables due to the high collinearity between the two. Therefore, one may need to consider their impacts gradually and with more advanced methodological approaches to obtain more proper results.

Lastly, the methodological approaches used by previous studies raise some serious estimation issues. First, these studies have made use of cross-sectional or panel data approaches in their empirical analyses. The studies that rely on cross-sectional data (Knowles and Owen, 1995, 1997; Rivera and Currais, 1999a; Webber, 2002) have used the average growth rate of income—mostly between the years 1960-1985 or 1960-1990—as the dependent variable, and have fixed the initial income level around 1960. In this way, these cross-sectional studies have (i) omitted unobservable factors from their regressions, which include technological differences across countries and other factors related to income growth, and (ii) ignored the time variation in the data by implicitly assuming that the parameters and variables related to growth and the evolution of the unobservable factors, including the growth rate of technology, are constant over the sample period. Moreover, these studies have aimed to examine the growth implications of health over some subsequent 25- or 30-year period by improperly fixing the values of health indicators at a last or initial year when infant mortality was mostly high (Arora, 2001: 704).

On the other hand, studies using a panel data framework have employed either pooled and static panel methodologies (Heshmati, 2001; Li and Huang, 2009; McDonald and Roberts, 2002) or an IV approach, 2SLS, and difference GMM estimators in their analyses (Bane, 2018; Bloom *et al.*, 2004; Caselli *et al.*, 1996; Gyimah-Brempong and Wilson, 2004; Rivera and Currais, 1999b). However, pooled and static panel methodologies, respectively, result in a heterogeneity bias and a

serious endogeneity bias due to the simultaneity between growth variables (Hsiao, 2014; Nickell, 1981). In addition, although this endogeneity bias has been partly eliminated through the use of instruments in the studies of Rivera and Currais (1999b) and Bloom *et al.* (2004), the validity of their instruments remains questionable. Furthermore, the studies using the IV approach, the 2SLS estimator, and the difference GMM seriously suffer from finite sample bias and poor instrumentation problems in short panels (Blundell and Bond, 2000; Blundell *et al.*, 2001; Mátyás and Sevestre, 2008). In short, from the viewpoint of both econometrics and growth empirics, the methodological approaches employed by the aforesaid studies are not suitable for the dynamic nature of the convergence argument and lead to severely biased estimates of Solow-convergence and health variables. In this sense, only two recent studies, Eggoh *et al.* (2015) and Sharma (2018), have used the system GMM estimator to examine population health as proxied by life expectancy at birth for African countries and only 17 advanced economies, respectively.

Given the discussion above, this study examines the effects of a healthy workforce on output growth and convergence. In particular, the study directly focuses on the productivity implications of health by differentiating between a healthy and unhealthy labor force in a country's production process. In this sense, the primary aim of the study is to obtain a theory-backed convergence equation that highlights the absenteeism implications of ill health on output growth. To this end, in the theoretical part, the study uses a narrowed Solow model that allows only healthy workers to be employed in production but not the whole labor force. This model is further extended to include the government, whose expenditures are assumed to be endogenous and have a positive externality effect on the production process. In the empirical part, the study employs a dynamic panel data approach to estimate the derived convergence equation and show the growth impacts of the share of healthy working hours and the health status of the workers at specific ages. Thus, the main heterogeneity between this study and the mainstream literature is related to the differences in the theoretical specification, the way the concept of health is defined in the theoretical model, the empirical specification, the applied methodology, and the health proxies used in the analyses.

Therefore, deviating from previous studies, first, the study uses a theory-based approach on convergence modeling, following Mankiw *et al.* (1992), to consider all significant insights of neoclassical theory, some of which are neglected in the absence of a formal theoretical derivation as discussed above. Second, in the previous theory-based convergence studies, the traditional approach was to include a health and an educational human capital accumulation function into the Solow model by allowing for the two forms of capital, physical and human. Unlike those studies, this study allows only healthy workers to be included in the production process by defining health precisely through the health of a country's workforce rather than its population. Hence, instead of focusing on the broadly used concept of human capital, this study directly considers the healthy part of the labor force and focuses on its growth implications by deviating from Mankiw *et al.* (1992)-type human capital modeling.¹⁶

To my best knowledge, there is only one theoretical growth study, which proposes to model the labor supply decisions of each worker as a function of the worker's health status. In this context, Muysken *et al.* (1999) were the first to theoretically augment the Ramsey (1928) growth model by suggesting a distinction between healthy and unhealthy workers. In their study, they examined the trade-off between optimal health expenditures, consumption, and physical capital by adding a healthy workers' accumulation function into the model. Hence, their study provides a theoretical background for considering the healthy share of the labor force in the production process of a country. However, unlike Muysken *et al.* (1999), this study exploits the Solow (1956) model and derives a convergence equation to empirically examine the effects of a healthy labor force on productivity growth. Furthermore, the model in the study is extended to examine the externality effects of government expenditures, which are met by a flat income tax rate in the model.

Third, in the empirical part, the study employs a more robust and efficient dynamic panel data estimator, the system GMM, to overcome the shortcomings of other methodological approaches. Hence, the methodology used in the study directly relates to the dynamic nature of the convergence argument and considers (i) the

¹⁶ Furthermore, these studies commonly assume that both physical and human capital have different savings rates but the same depreciation rates, which in fact leads to an incomplete empirical explanation of how human capital accumulates, as the depreciation rate for human capital is still unknown, *e.g.*, there is still no satisfactory data on the morbidity rates.

differences in the level of technology, (ii) the evolution of technology growth that is common to all sample countries, (iii) the differences in other unobserved growth-related factors across countries, and (iv) the issue of a possible endogeneity. Therefore, it provides more accurate and unbiased estimates of Solow-convergence and health variables compared to previous studies. Fourth, this study employs a few health measures related to the working population of a country instead of the data that was more typically used previously. Instead of proxying workers' health using population health measures like previous studies, this study includes the share of healthy working hours, life expectancies at ages 15 to 60, and adult mortality rates between ages 15 and 60. Hence, by doing so, the study directly focuses on the productivity and growth implications of sickness absence and the age-specific health status of the workforce.

The empirical estimations are further controlled by human capital in the form of education, trade openness, and fiscal policy variables including the income tax rate, government expenditures, and tax revenues. Fifth, the study explores the growth-health nexus within the scope of OECD countries, for which the empirical evidence is still controversial. Hence, studying the nexus between health and growth seems highly valuable, particularly in the context of high-income countries, to further discover this nexus with more accurate and refined indicators of health and methodological approaches (Caselli, 2005; Suhrcke *et al.*, 2006; Tompa, 2002). Lastly, the study updates the basic empirical results to the late 2010s. Therefore, compared to other related studies, the sample used in the study covers a relatively long period of time to examine the out-of-steady-state dynamics of per-worker output.

1.3. A SOLOVIAN ECONOMY WITH HEALTHY LABOR

Consider a closed Solovian economy as a special case of the standard Ramsey-type growth model with an exogenous savings rate.¹⁷ Two modifications are added to this standard model. First, à la Muysken *et al.* (1999), it is assumed that in this hypothetical economy, the labor supply of each worker is a function of the worker's health status (Muysken *et al.*, 1999: 4). That is, a share of the labor force is allowed to

¹⁷ The next chapter deals with the Ramsey (1928) model, which considers the consumption-savings trade-off endogenously.

be absent from work due to ill health, and only the healthy labor force is allowed to be engaged in production activities at any instant of time. Second, this model that has been shortened to include only healthy workers is then extended by the presence of a generous government, whose expenditures are assumed to generate a positive externality effect on the whole production process of the firms. That is, this study provides two versions of the Solow (1956) model: (i) at the outset, the model assumes that the production process of a country includes only healthy workers and that there is no government, as in the original Solow model ($G_t = 0$), and then (ii) the former model is extended to include the government ($G_t = \bar{\tau} \cdot Y_t = TAXR_t$).¹⁸ Hence, based on the above assumptions, suppose first that the standard Cobb-Douglas (C-D) production function with constant returns to scale (CRS) is defined as follows:^{19,20}

$$Y_t = K_t^\alpha \cdot (T_t \cdot L_{Ht})^{1-\alpha} \quad (1)$$

In equation (Eq.) (1), Y_t is the total output²¹, K_t is the physical capital, L_{Ht} is the healthy labor force actively taking place at any instant in the production process, and the subindex t represents time. The parameters α and $1 - \alpha$ represent the production elasticities, or equivalently, the income shares of physical capital and an effective (healthy) labor force, respectively, and $0 < \alpha < 1$. T_t is the overall technological progress defined as $T_t = T_0 \cdot e^{\omega t}$, $T_t > 0$, and ω is the exogenous growth rate of technological progress. The growth literature has shown that in cases where the growth rates of population (or workforce) and technological progress are constant, the technology T_t should be introduced in a labor-saving form into the production process to obtain steady-state outcomes (Barro and Sala-i-Martin, 2004; Phelps, 1966; Swan, 1964). Hence, in Eq. (1), the technology T_t has been employed in a labor-augmenting form following the definition of Harrod (1942).

¹⁸ A bar on top of τ “ $\bar{\tau}$ ” means that it is determined exogenously and takes a constant value.

¹⁹ The C-D function guarantees that all factors of production, one of which is a healthy labor force in this model, are essential. The homogeneity of degree one characteristic of the C-D form also ensures that the real profit is zero, which is a salient feature of perfectly competitive markets. Moreover, Barro (1990) has further stated that the assumption of CRS is reasonable when capital is viewed broadly to include physical and human capital (Barro, 1990: 105).

²⁰ Each variable with a subindex t is a function of time.

²¹ Following Solow (1956), in this section, real output and/or real income are used interchangeably to define Y_t (Solow, 1956: 66).

The total labor force is traditionally given by $L_t = L_0 \cdot e^{nt}$, where n represents the exogenous growth rate of the labor force and $n \geq 0$.²² However, as given in Eq. (1), the total labor stock in this hypothetical economy is divided into two parts, healthy L_{Ht} and unhealthy ones L_{UHt} . L_{Ht} shows a healthy labor force and is represented by a constant and exogenous share of the total labor force, $L_{Ht} = \phi_H \cdot L_t$, where $0 < \phi_H < 1$. Note that the original Solow (1956) model assumes that ϕ_H is always equal to one, *i.e.*, all workers are always in an ideal health status. Furthermore, without loss of generality, the model practically presumes that the healthy labor force is always less than the total labor force available in an economy, $L_{Ht} < L_t$. In parallel, L_{UHt} is some part of the labor stock that is absent from work due to ill health, $L_{UHt} = (1 - \phi_H) \cdot L_t$. Hence, the total workforce of a country is given by $L_t = L_{Ht} + L_{UHt}$, in which unhealthy ones are not engaged in production activities due to sickness absence until they heal, and the total workforce actually used in production only refers to the sum of healthy workers. The healthy and total labor force are further assumed to grow at the same rate, n , which implies that ϕ_H is constant in time. Given that the main aim of this chapter is to develop a testable output convergence equation that measures the role of healthiness on economic growth rather than to explain the sources of (un)healthiness, this constancy assumption is an innocent and acceptable assumption.

Following the CRS property of the production function, the aggregate production function in Eq. (1) and the fundamental equation of growth, $\dot{K}_t = s_K \cdot Y_t - \delta K_t$, are first expressed in effective labor terms ($T_t \cdot L_t$) as follows:

$$\check{y}_t = \check{k}_t^\alpha \cdot \phi_H^{1-\alpha} \quad (2)^{23}$$

$$\dot{\check{k}}_t = s_K \cdot \check{k}_t^\alpha \cdot \phi_H^{1-\alpha} - (n + \omega + \delta) \cdot \check{k}_t \quad (3)$$

where $\check{y}_t = \frac{Y_t}{T_t \cdot L_t}$, $\check{k}_t = \frac{K_t}{T_t \cdot L_t}$, and $\phi_H = \frac{L_{Ht}}{L_t}$. Eq. (3) shows the dynamics of the effective physical capital per labor, in which s_K is the exogenous savings rate of physical capital, $\check{k}_t^\alpha \cdot \phi_H^{1-\alpha}$ is the intensive form of the production function given in Eq. (2), and $(n + \omega + \delta)$ gives the effective depreciation rate as the sum of the exogenous rates of

²² Since the Solow (1956) model ignores the value of leisure, the total population is assumed to be equal to the total labor force in a country, which is not the case in practice.

²³ The grave “ $\check{}$ ” on the variables means that the variable is expressed in effective labor terms.

the labor force growth (n), the growth of technological progress (ω), and the depreciation of physical capital ($\delta \geq 0$).

The solution to the model is as follows: Based on the assumption of the existence of a steady state, the long-run equilibrium solution of the model shows that the steady-state value of effective capital per worker can be obtained as $\tilde{k}^s = \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{1}{1-\alpha}} \cdot \phi_H$.^{24,25} This implies that the steady-state values of output and consumption per unit of effective labor can also be obtained as $\tilde{y}^s = \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot \phi_H$ and $\tilde{c}^s = (1 - s_K) \cdot \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot \phi_H$. Hence, it can be clearly shown that steady-state values of per-worker variables can also be given as follows:

$$k^s = \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{1}{1-\alpha}} \cdot \phi_H \cdot T_0 \cdot e^{\omega t} \quad (4)$$

$$y^s = \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot \phi_H \cdot T_0 \cdot e^{\omega t} \quad (5)$$

$$c^s = (1 - s_K) \left(\frac{s_K}{n+\omega+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot \phi_H \cdot T_0 \cdot e^{\omega t} \quad (6)$$

Equations (Eqs.) (4) – (6) clearly show that (i) the long-run equilibrium values of per-worker variables are lower than the values obtained from the solution of the standard Solow model, in which the entire labor stock is assumed to have an ideal health status at any instant of time (*i.e.*, $\phi_H = 1$), (ii) in the long run, an increase (decrease) in the share of (un)healthy workers ϕ_H clearly raises per-worker equilibrium values of physical capital $\frac{\partial k^s}{\partial \phi_H} > 0$, real output $\frac{\partial y^s}{\partial \phi_H} > 0$, and also consumption $\frac{\partial c^s}{\partial \phi_H} > 0$, and (iii) in the long run, per-worker values of physical capital, output, and consumption all grow at the rate of technological progress ω , $\frac{\dot{k}^s}{k^s} = \frac{\dot{y}^s}{y^s} = \frac{\dot{c}^s}{c^s} = \frac{\dot{T}_t}{T_t} = \omega$. In other words, although the growth rates of these per-worker variables

²⁴ The superscript “s” over a variable shows the steady-state value of that variable.

²⁵ All detailed solutions and derivations are provided in Appendix 1. Although it mainly includes solutions from the second model with government, solutions of the former model can be easily followed through the latter.

are different in the transitional period, they all start to grow at a constant rate of ω at infinity. Hence, the results of this narrowed model also confirm the main prediction of the basic Solow model, *i.e.*, that technological progress is the main engine of long-run economic growth. Moreover, the solution of the model shows the determinants of the steady-state output, one of which is now the share of a healthy labor force. That is, Eq. (7) below can be used for studying long-run determinants of real output per worker, which is a shortened version (that is, it includes only healthy workers) of Eq. (11) given in the pioneering paper of Mankiw *et al.* (1992: 417).

$$\ln(y^s) = \left(\frac{\alpha}{1-\alpha}\right) \ln(s_K) - \left(\frac{\alpha}{1-\alpha}\right) \ln(n + \omega + \delta) + \ln(\phi_H) + \ln(T_0) + \omega t \quad (7)$$

Additionally, to mention the real wage and interest rate implications of the model, one can solve the profit maximization problem of the firm. In this sense, the representative firm's flow of profits π_t is given by $\pi_t = K_t^\alpha \cdot (T_t \cdot L_{Ht})^{1-\alpha} - (r_t + \delta) \cdot K_t - w_t \cdot L_{Ht}$. The first-order conditions of profit maximization show that, under the assumption of exogenous technology, the wage rate and the interest rate are given by these equations, $w_t = (1 - \alpha) \cdot \tilde{k}_t^\alpha \cdot \phi_H^{-\alpha} \cdot T_t$ and $r_t = \alpha \tilde{k}_t^{\alpha-1} \cdot \phi_H^{1-\alpha} - \delta$. Their respective steady-state values are $w^s = (1 - \alpha) \cdot \left(\frac{s_K}{n + \omega + \delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot T_0 \cdot e^{\omega t}$ and $r^s = \alpha \cdot \left(\frac{n + \omega + \delta}{s_K}\right) - \delta$. Hence, it can be noticed that at any point in time, the solutions on real wages and interest rates are different from the standard results of the Solow model. An increase in the parameter ϕ_H results in a decrease in the real wage rate, as expected, and an increase in the real interest rate. However, at the long-run equilibrium, the real wage continues to increase at a rate equal to the rate of technological progress ω , while the real interest rate reaches a constant value, as in the Solow model.

Next, as the main aim of this study, a testable output convergence equation is obtained to empirically examine the growth implications of a healthy labor force. First, the fundamental equation of growth in Eq. (3) is re-expressed in terms of output per unit of effective labor $\tilde{y}_t$ and then a log-linear approximation is applied around its steady-state position. Accordingly, the log differentiation of the intensive form of the

production function and a simple substitution for $\check{k}_t$ yield the following nonlinear differential equation in terms of $\check{y}_t$:

$$\frac{\dot{\check{y}}_t}{\check{y}_t} = \alpha \left[s_K \cdot \check{y}_t^{\frac{\alpha-1}{\alpha}} \cdot \phi_H^{\frac{1-\alpha}{\alpha}} - (n + \omega + \delta) \right] \quad (8)$$

Eq. (8) is rearranged to obtain a univariate function of $\ln(\check{y}_t)$, that is, $\frac{d\ln(\check{y}_t)}{dt} = \alpha \left[s_K \cdot e^{\left(\frac{\alpha-1}{\alpha}\right)\ln(\check{y}_t)} \cdot \phi_H^{\frac{1-\alpha}{\alpha}} - (n + \omega + \delta) \right] \equiv \psi[\ln(\check{y}_t)]$. After log linearization through first-order Taylor series expansion, this equation becomes

$$\frac{d\ln(\check{y}_t)}{dt} \approx -(1 - \alpha)(n + \omega + \delta)[\ln(\check{y}_t) - \ln(\check{y}^s)] \quad (9)$$

Hence, Eq. (9) gives the log-linearized version of Eq. (8) around the steady-state position. In Eq. (9), if the first term in the RHS of the equation is defined as $\lambda = (1 - \alpha)(n + \omega + \delta)$, then it is straightforward to show that $\frac{d(\dot{\check{y}}_t/\check{y}_t)}{d\ln(\check{y}_t/\check{y}^s)} \cong -\lambda$. Hence, $-\lambda$ gives the convergence rate that shows the rate at which an economy approaches its steady state. Here, it should be noted that the share of the healthy labor force (ϕ_H), which is assumed to be constant in time and treated as an exogenous productivity parameter in the model setup, does not appear in the expression of the convergence coefficient. Hence, precisely for this reason, the assumption on its constancy is innocent in the sense that it is compatible with the neoclassical conditional convergence argument.²⁶ The rest of the derivations follow the standard algebra as given in Appendix 1, through which one can obtain the conditional convergence equation with the share of the healthy workers as in Eq. (10) below:

²⁶ In reality, the share of the healthy labor force, ϕ_H and/or any proxy variable that shows the health status of the workforce are neither constants nor exogenous. In fact, health status and income, as well as other Solow growth variables, significantly and mutually affect each other. The implications of this interrelationship are discussed in the next section on empirical estimations.

$$\begin{aligned}
\ln(y_{t_2}) - \ln(y_{t_1}) = & -(1 - e^{-\lambda\tau})\ln(y_{t_1}) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\alpha}\right)\ln(s_K) - \\
& (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\alpha}\right)\ln(n + \omega + \delta) + (1 - e^{-\lambda\tau})\ln(\phi_H) + (1 - e^{-\lambda\tau})\ln(T_0) + \omega(t_2 - t_1)
\end{aligned} \tag{10}$$

where y_t is the real output per worker and $\ln(y_{t_2}) - \ln(y_{t_1})$ refers to the average growth rate of output per worker between two time points. Following Islam (1995), t_1 and t_2 are assumed to be two points in time such that $t_2 > t_1$ and $\tau = t_2 - t_1$. The determinants of per worker output growth are on the RHS of the equation, including the initial output per worker at the beginning of each τ -year period (y_{t_1}), the savings rate (s_K), the augmented rate of workforce growth ($n + \omega + \delta$), the healthy share of the total workforce (ϕ_H), the level of initial technology (T_0), and the growth rate of technological progress (ω).

Eq. (10) is consistent with the growth literature on conditional convergence (Barro and Lee, 1993; Barro and Sala-i- Martin, 2004; Islam, 1995; Knowles and Owen, 1995, 1997; Mankiw *et al.*, 1992). It implies that due to diminishing returns on physical capital, the growth rate of a country declines (increases) as it approaches (becomes distant from) its own steady state, which in turn depends on other structural characteristics of that country. Some of these structural characteristics are given in the RHS of Eq. (10), one of which is the share of a healthy labor force in this case. It shows that the share of a healthy labor force has a positive contribution to output growth during the convergence process, if it exists.

When compared to the full-health Solow model (*i.e.*, $\phi_H = 1$), the loss in output growth due to ill health can be clearly shown by the parameter ϕ_H , which is defined as $0 < \phi_H < 1$. Therefore, Eq. (10) further indicates a direct and positive impact of workforce healthiness on productivity. It shows that the improvements in workers' health status decrease absent time from work and increase the size of the active workforce (L_{Ht}), which can be directly translated into increases in labor productivity in the aggregate. In other words, improvements in workforce healthiness both in physical and mental terms directly increase annual production of output through lower rates of absenteeism. If extended to a cross-country context, one could

argue that increases in the share of healthy workers in the countries will help to reduce per-worker output disparities over time.

After purely focusing on the growth implications of workforce healthiness, the government is included in the above model. Hence, as a second step, it is assumed that a balanced-budget government $G_t = TAXR_t$ collects tax revenue ($TAXR_t$) via income tax with a flat rate of $\bar{\tau}$ to spend on goods and services, including transportation, roads, infrastructure, health expenditures, services, *etc.* The private sector benefits from these public goods and services and does not bear any extra cost for these expenditures made by the government. In this sense, the government affects the production process of firms positively by providing goods and services, but at the expense of income taxes, $G_t = \bar{\tau} \cdot Y_t = TAXR_t$.^{27,28} Hence, precisely for this reason, government expenditures have a positive externality effect on the production process of firms, which was first assumed and introduced by the study of Barro (1990) to explain how the positive externality effect of government spending leads to endogenous growth.

Given the preceding discussion, the intensive form of the production function in Eq. (2) extended with government spending is now defined as $\tilde{y}_t = \tilde{k}_t^\alpha \cdot \phi_H^{1-\alpha} \cdot \tilde{g}_t^\vartheta$, where $0 < \vartheta < 1$. Hence, in the presence of a balanced budget government, Eqs. (2) and (3) can be re-expressed as follows:

$$\tilde{y}_t = \tilde{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}} \quad (11)$$

$$\dot{\tilde{k}}_t = s_K(1 - \bar{\tau}) \cdot \tilde{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}} - (n + \omega + \delta) \cdot \tilde{k}_t \quad (12)$$

Eqs. (11) – (12) show the production function and the physical capital accumulation equation in effective labor terms, respectively. The solution procedure is the same as that of the former model, and all the detailed derivations are provided in Appendix 1.

²⁷ It is possible and straightforward to model government expenditures as an element or a positive externality that backs only the labor force or the share of healthy workers in the model. In this case, these expenditures will only include public health expenditures or other goods and services that indirectly affect workers' health positively, including more green areas, healthy and sustainable transportation services, healthy working spaces, *etc.* However, since these effects of public expenditures are discussed in the context of health investments in Chapter 2, this chapter studies the total government expenditures assumed to have a positive externality effect on the entire production process.

²⁸ Note that in the above model, the tax rate does not ensure the existence of a balanced budget. Rather, output and government expenditures are assumed to be endogenous variables, and the tax rate is exogenous. Hence, the income tax rate determines only the amount of government spending.

Briefly, based on the assumption of the existence of a steady state, the long-run equilibrium solutions of per-worker variables can be given as in Eqs. (13) – (16):

$$k^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{1-\vartheta}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (13)$$

$$y^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (14)$$

$$c^s = (1 - s_K)(1 - \bar{\tau})^{\frac{1-\vartheta}{1-\vartheta-\alpha}} \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (15)$$

$$g^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (16)$$

Eqs. (13) – (16) show that (i) the long-run equilibrium values of per worker variables are again lower than the values obtained from the solution of the standard Solow model, in which $\phi_H = 1$, (ii) in the long run, an increase (a decrease) in the share of (un)healthy workers ϕ_H clearly raises per worker values of physical capital $\frac{\partial k^s}{\partial \phi_H} > 0$, real output $\frac{\partial y^s}{\partial \phi_H} > 0$, consumption $\frac{\partial c^s}{\partial \phi_H} > 0$, and also government expenditures $\frac{\partial g^s}{\partial \phi_H} > 0$, and (iii) all per worker variables grow at a rate of the technological progress (ω) at the long-run equilibrium, $\frac{\dot{k}^s}{k^s} = \frac{\dot{y}^s}{y^s} = \frac{\dot{c}^s}{c^s} = \frac{\dot{g}^s}{g^s} = \frac{\dot{taxr}^s}{taxr^s} = \frac{\dot{T}_t}{T_t} = \omega$.²⁹ In the absence of externality generated by government expenditures, one can easily show the welfare loss in the economy depending on the rate of income taxes, as implied by Eq. (15). In the presence of a production externality, however, increases in the income tax rate reduce capital accumulation and disposable income, as long as $\frac{1-\vartheta}{\vartheta} < \frac{1-\bar{\tau}}{\bar{\tau}}$, where the long-run equilibrium value of disposable income is $y_d^s = (1 - \bar{\tau})^{\frac{1-\vartheta}{1-\vartheta-\alpha}} \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t}$. Of course, in the absence of an externality, per-worker values of physical capital and output have a lower steady-state value compared to the tax-free case as given in Eqs. (4) and (5).

Furthermore, the critical value of the income tax rate that optimizes consumption per worker at the steady state can be determined by taking the first partial

²⁹ g and $taxr$ define the per-worker values of the respective variables.

derivative of Eq. (15) with respect to the income tax rate, which is equal to $\bar{\tau}^* = \vartheta$. In other words, for a closed economy with a balanced-budget government (if it exists), the results of the theoretical model imply that the income tax rate should be equal to the elasticity of income with respect to government expenditures in order to optimize per-worker consumption expenditures at steady state. The solution of the model also shows that the long-run determinants of real output per worker can be given as follows:

$$\ln(y^s) = \left(\frac{\alpha}{1-\vartheta-\alpha}\right) \ln(s_K) + \left(\frac{\alpha}{1-\vartheta-\alpha}\right) \ln(1 - \bar{\tau}) - \left(\frac{\alpha}{1-\vartheta-\alpha}\right) \ln(n + \omega + \delta) + \left(\frac{1-\alpha}{1-\vartheta-\alpha}\right) \ln(\phi_H) + \left(\frac{\vartheta}{1-\vartheta-\alpha}\right) \ln(\bar{\tau}) + \ln(T_0) + \omega t \quad (17)$$

Once again, to obtain a testable output convergence equation, Eqs. (11) and (12) are used to derive the following nonlinear differential equation in terms of $\tilde{y}_t$:

$$\frac{\dot{\tilde{y}}_t}{\tilde{y}_t} = \frac{\alpha}{1-\vartheta} \left[s_K \cdot (1 - \bar{\tau}) \cdot \tilde{y}_t^{\frac{\alpha+\vartheta-1}{\alpha}} \cdot \phi_H^{\frac{1-\alpha}{\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{\alpha}} - (n + \omega + \delta) \right] \quad (18)$$

The rest of the derivations follow the standard convergence algebra. By using first-order Taylor expansion, Eq. (18) is log-linearized around the steady-state position. Thus, it is straightforward to show that

$$\frac{d \ln(\tilde{y}_t)}{dt} \approx - \left(\frac{1-\alpha-\vartheta}{1-\vartheta} \right) (n + \omega + \delta) [\ln(\tilde{y}_t) - \ln(\tilde{y}^s)] \quad (19)$$

If λ is defined as $\lambda = \left(\frac{1-\alpha-\vartheta}{1-\vartheta} \right) (n + \omega + \delta)$, then λ gives the convergence rate in this case. Hence, by solving this linear differential equation and assuming that t_1 and t_2 are two points in time such that $t_2 > t_1$ and $\tau = t_2 - t_1$, one can end up with the following conditional convergence equation:

$$\begin{aligned}
\ln(y_{t_2}) - \ln(y_{t_1}) = & -(1 - e^{-\lambda\tau})\ln(y_{t_1}) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(s_K) + \\
& (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(1 - \bar{\tau}) - (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(n + \omega + \delta) + \\
& (1 - e^{-\lambda\tau})\left(\frac{1-\alpha}{1-\vartheta-\alpha}\right)\ln(\phi_H) + (1 - e^{-\lambda\tau})\left(\frac{\vartheta}{1-\vartheta-\alpha}\right)\ln(\bar{\tau}) + (1 - \\
& e^{-\lambda\tau})\ln(T_0) + \omega(t_2 - e^{-\lambda\tau}t_1)
\end{aligned} \tag{20}$$

Eq. (20) shows the impact of the share of a healthy workforce and the tax rate on the growth of output per worker and the convergence process. The next section deals with the empirical part of the convergence analysis, in which a dynamic panel data version of Eqs. (10) and (20) is gradually employed.

1.4. EMPIRICAL METHODOLOGY, DATA, AND FINDINGS

Eq. (20) is reorganized to obtain an operational empirical model that measures the contribution of a healthy labor force and the positive externality effect of government spending to output growth and convergence:

$$\begin{aligned}
\ln(y_{it}) - \ln(y_{i,t-1}) = & \gamma_1 \ln(y_{i,t-1}) + \gamma_2 \ln(s_{Kit}) + \gamma_3 \ln(n_{it} + \omega + \delta_{it}) + \\
& \gamma_4 \ln(\phi_{Hit}) + \gamma_5 \ln(1 - \tau_{it}) + \gamma_6 \ln(\tau_{it}) + \theta \ln(X_{it}) + \varphi_i + \zeta_t + v_{it}
\end{aligned} \tag{21a}$$

In Eq. (21a), the dependent variable is the log difference of real output per worker over a τ -year period.³⁰ $\gamma_1 = -(1 - e^{-\lambda\tau})$ is the coefficient of the log of real output per worker over the previous τ -year span and theoretically expected to be negative in order to be consistent with the convergence idea. $\gamma_2 = (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)$ is the coefficient of the savings rate and is expected to be positive. $\gamma_3 = -(1 -$

³⁰ One of the main sources of heterogeneity across empirical growth studies is the specification of the dependent variable in the convergence regression. Most studies in the related literature have used the log-difference of real income per capita or worker over some τ -year period as the dependent variable (Barro, 1996a; Bloom *et al.*, 2004; Bond *et al.*, 2001; Caselli *et al.*, 1996; Ding and Knight, 2009; Gyimah-Brempong and Wilson, 2004; Heshmati, 2001; Knowles and Owen, 1995; Rivera and Currais, 1999a, 1999b; Webber, 2002), while others have used the log-level of real income at the end of each τ -year period (Islam, 1995; Knowles and Owen, 1997; Li and Huang, 2009; McDonald and Roberts, 2002). Since this study aims to examine the effects of healthiness on output growth, the growth setup is followed in the study.

$e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)$ shows the effect of the augmented growth rate of the labor force on economic growth.³¹ The coefficient $\gamma_4 = (1 - e^{-\lambda\tau})\left(\frac{1-\alpha}{1-\vartheta-\alpha}\right)$ measures the contribution of the health indicators to per-worker output growth, which are alternately used as proxies for the share of a healthy workforce and for the health status of the total workforce in the study.³²

In this sense, three health proxies are used in the empirical analyses: the share of healthy working hours in total working hours, the life expectancy at specific ages from 15 to 60, and adult mortality at ages between 15 and 60. It is expected that good (ill) health, as measured by increases in the share of healthy working hours and age-specific longevity (increases in adult mortality), will boost (decrease) economic growth. In several studies on income convergence, it has been concluded that, compared to the basic Solow model, the estimated rates of convergence further increase with the inclusion of human capital indicators (Hoeffler, 2002; Islam, 1995; Mankiw *et al.*, 1992; McDonald and Roberts, 2002; Rivera and Currais, 1999a). Therefore, since a lower γ_1 (a higher γ_1 in absolute value) indicates the presence of faster convergence, it is expected that the inclusion of health indicators will increase the estimated value of γ_1 in absolute value and, hence, the estimated rate of output convergence compared to the rates obtained from the estimation of the basic Solow model given in Eq. (21c) below.

The coefficient $\gamma_5 = (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)$ shows the effect of the shortfall of the income tax rate from one. Theoretically, $(1 - \bar{\tau})$ implicitly includes the share of savings, consumption, and net exports in total income given the macroeconomic budget constraint that $Y_t = C_t + I_t + G_t + NX_t$. The coefficient $\gamma_6 = (1 - e^{-\lambda\tau})\left(\frac{\vartheta}{1-\vartheta-\alpha}\right)$ measures the effect of the income tax rate ($\bar{\tau}$) on output growth.³³

³¹ In the literature, a common practice is to assume a constant 5 percentage rate for the sum of $\omega + \delta$. However, in this study, the depreciation rate on physical capital is allowed to vary across countries and time (δ_{it}) and ω is assumed to be constant at 2 percent.

³² In the theoretical model, although it is assumed that the share of the healthy labor force is constant over time, from an empirical point of view, it is obviously not. Hence, in empirical models, ϕ_H is expressed with a cross-section and a time subscript, ϕ_{Hit} .

³³ Similarly, although it is theoretically assumed that the income tax rate is constant over time, practically, it is not. As a result, in empirical models, $\bar{\tau}$ is denoted by a cross-section and a time subscript, τ_{it} .

However, by definition, it also shows the share of total government expenditures or tax revenue in total income, *i.e.*, $\bar{\tau} = \frac{G_t}{Y_t} = \frac{TAXR_t}{Y_t}$. Therefore, the study uses the income tax rate and its shortfall in the empirical analyses and further includes the share of government expenditures and the share of total tax revenue in GDP as proxies for $\bar{\tau}$ in the empirical estimations. X_{it} shows the vector of control variables and θ represents the coefficients of the control variables. Hence, the study further employs two control variables, human capital in the form of education and trade openness, to partly eliminate the issues of omitted variable bias in the estimations. $\varphi_i = (1 - e^{-\lambda\tau}) \ln(T_0)$ and $\zeta_t = \omega(t_2 - e^{-\lambda\tau}t_1)$ measure country- and time-specific fixed effects, respectively. In fact, φ_i captures unobserved effects on total factor productivity (TFP) due to country-specific omitted factors and ζ_t corresponds to the impact of macroeconomic shocks on output growth, which are assumed to commonly occur during the period t_i in all sample countries. That is, in the empirical estimations, the study assumes identical but not constant technological growth across countries. Lastly, v_{it} refers to the error component, i indicates cross-sectional units, and t denotes time points.

In the estimations, the study employs four different versions of Eq. (21a). As the main aim of this study is to focus directly on the growth implications of a healthy workforce, first, the study employs a dynamic panel data version of Eq. (10). Note that in Eq. (21b), the specification of some γ coefficients changes, *i.e.*, $\gamma_2 = -\gamma_3 = (1 - e^{-\lambda\tau}) \left(\frac{\alpha}{1-\alpha}\right)$ and $\gamma_4 = (1 - e^{-\lambda\tau})$ in this case.

$$\ln(y_{it}) - \ln(y_{i,t-1}) = \gamma_1 \ln(y_{i,t-1}) + \gamma_2 \ln(s_{Kit}) + \gamma_3 \ln(n_{it} + \omega + \delta_{it}) + \gamma_4 \ln(\phi_{Hit}) + \theta \ln(X_{it}) + \varphi_i + \zeta_t + v_{it} \quad (21b)$$

Then, following the common practice in growth empirics, two other versions of Eq. (21a) are also estimated, first by ignoring the effects of health and government indicators (the basic Solow model), and then by employing the unconditional version of it as follows:

$$\ln(y_{it}) - \ln(y_{i,t-1}) = \gamma_1 \ln(y_{i,t-1}) + \gamma_2 \ln(s_{Kit}) + \gamma_3 \ln(n_{it} + \omega + \delta_{it}) + \varphi_i + \zeta_t + v_{it} \quad (21c)$$

$$\ln(y_{it}) - \ln(y_{i,t-1}) = \gamma_1 \ln(y_{i,t-1}) + \varphi_i + \zeta_t + v_{it} \quad (21d)$$

Herewith, Eqs. (21d), (21c), (21b), and (21a) are employed in turn to examine (i) whether there exists a catch-up process between sample countries independent of the structural parameters such as tastes, technology, health, and fiscal policy variables, *i.e.*, whether the countries converge in an absolute sense, (ii) whether there exists a conditional convergence process between structurally similar countries if the health and policy indicators are ignored in the estimations, (iii) whether there is evidence of convergence conditional on the effects of workforce healthiness and the control variables, and (iv) the effects of workforce healthiness and government on the growth and convergence process controlled by educational human capital and openness to trade. Comparatively, the highest convergence rates are expected to be obtained from the estimations of Eqs. (21a) and (21b) and the lowest from the estimation of Eq. (21d).

1.4.1. Empirical Methodology

Each equation (21a) – (21d) is estimated using a panel framework due to its advantages over time-series and cross-sectional data. From an empirical growth standpoint, the time-series framework focuses on an individual country and falls short of testing the compatibility of the theory for large country groups. It also limits the ability to draw broad conclusions about long-run economic growth in terms of policy relevance. Furthermore, using this framework results in short-run variation in the growth rates being captured by business cycle effects. Therefore, growth studies are generally concentrated around panel and cross-sectional data models, although there have been serious initial efforts to incorporate time-series data into the empirical growth literature (Bernard and Durlauf, 1995; Binder and Pesaran, 1999; Evans and Karras, 1996; Lee *et al.*, 1997; Lowey and Papell, 1996; Quah, 1990). In this sense, the main advantage of using panel data is that it allows one to capture the short-run dynamics for a large number of countries, which is not possible to handle with time-series data as in the case of cross-sectional data.

The cross-sectional framework considers long-run transitional dynamics instead of short-run effects. However, since the convergence equation is derived by applying a first-order Taylor approximation as in Eqs. (10) and (20), this framework is valid only in the neighborhood of the steady state. Therefore, using cross-sectional data and related methodologies by applying very long time intervals (*e.g.*, 25 or 50-year averages) are not suitable for testing the existence of a possible convergence across countries. Furthermore, using this framework leads to serious estimation problems due to its assumptions that the determinants of growth, including the growth rate of technology, are constant in time, the omission of fixed effects, and the inclusion of the lagged dependent variable among other explanatory variables. Hence, this study uses a panel data framework, which is often regarded as the best way to obtain consistent estimates of a conditional convergence regression, especially in the absence of a proxy for the level of technology (Temple, 1999: 123).

Accordingly, there are three issues worth explaining here. First of all, in most growth applications, a small number of time periods are considered to avoid periodic dynamics. If annual data is used by relying on macro-panel datasets, a serious effort is needed to model the short-run dynamics since some heterogeneity is inevitable in this case (Temple, 1999: 132). Therefore, à la Islam (1995), most of the growth studies relying on panel data use non-overlapping time points to express the time dimension of the sample data in the empirical analyses. The same tradition has been followed in this study for several reasons. Compared to yearly data, this setup allows (i) to reduce autocorrelation among residuals and (ii) to minimize the effects of temporary shocks related to cyclical business fluctuations (Bond *et al.*, 2001; Ding and Knight, 2009; Islam, 1995). Furthermore, although some databases recently provided nearly 70 years of data for growth variables, it is hard to find long-term annual data for other determinants of growth, including health. Therefore, in most cases and for this study, it is difficult to obtain a macro panel for growth estimation. In this sense, this study also employs a micro panel dataset by adopting this averaging setup.

Secondly, this study uses a dynamic approach to primarily meet the estimation requirements imposed by the inclusion of the lagged dependent variable in the RHS of the convergence regression equation. Therefore, Eqs. (21a) – (21d) are estimated by using a dynamic panel data estimator, the system GMM. This estimator allows for less

restrictive assumptions from an economic standpoint while providing more reliable estimates with its superior finite sample properties from an econometric perspective. It allows one to eliminate a few major shortcomings faced by cross-sectional and static panel estimators, including parameter constancy, unobserved heterogeneity, and endogeneity. It also offers a distinct advantage over other dynamic panel data estimators in terms of obtaining more efficient estimates by (i) including more instruments, (ii) improving precision for short panels, and (iii) reducing bias for finite samples in cases where the sample series are close to being random walks (Blundell and Bond, 2000; Roodman, 2009a). The last point raises the third issue, as follows.

The time-series properties of the growth variables are largely ignored in the standard cross-country growth regressions due to a belief that time averaging helps to eliminate non-stationary characteristics of the series. However, contrary to this belief, it has been argued that time-averaging does not avoid the problem of non-stationarity (Granger, 1988; Granger and Siklos, 1995). Moreover, testing for the stationarity properties of the variables is important to ensure the appropriateness of the dynamic panel data methodology even when the number of cross-sectional observations is much greater than the number of time-series observations. In this sense, Bond (2002) has stated that the time-series features are crucial to identify the parameters and finite sample properties of the GMM estimator, as this estimator can exhibit poor performance in cases when sample series are near being random walks (Bond, 2002: 143).

In terms of standard growth variables, Phillips and Moon (2000) have further argued that strong non-stationarity is evident in the time-series components of the variables in some panel data sets like the Penn World Table (PWT) (Phillips and Moon, 2000: 264). Furthermore, since any macro production function probably contains non-stationary input and output variables, their time-series properties need to be considered to avoid any possible bias, *i.e.*, a spurious correlation (Eberhardt and Teal, 2011: 133). Hence, it is apparent that there is a need to consider the time-series behavior of the panel, as the empirical part of this study deals with macroeconomic aggregates, for which the time-series dimension is relatively large compared to the cross-sectional one. To this end, as a first step, the stationarity properties of the variables are examined by using appropriate PURTs prior to the estimations in an

effort to avoid unreliable and spurious results. In this sense, the next two subsections discuss PURTs and the system GMM approach, respectively.

1.4.1.1. Panel Unit Root Tests

Many techniques have been developed to estimate the order of integration of the series in panel data. Some of these techniques include the first-generation PURTs, which share a common assumption on the existence of cross-sectional independence but significantly differ in several key aspects. In this context, consider the following simplified model that shows the production process of time-series data (y_{it}) on cross-sectional units in a simple form of D-F (Dickey-Fuller) regression:

$$\Delta y_{it} = \varphi_i y_{i,t-1} + v_{it} \quad (22)$$

where $t = 1 \dots T$ and $i = 1, \dots, N$. T refers to the time dimension of the panel, N represents the cross-sectional dimension, φ_i is the heterogeneous autoregressive parameter, and v_{it} is the error term, $v_{it} \sim i.i.d. (0, \sigma_i^2)$. Given Eq. (22), the null hypothesis in most unit root tests is given by $H_0: \varphi_i = \dots = \varphi_N = 0$, that is, each series in the panel contains a unit root, although there are two different alternative hypotheses such as $H_1: \varphi_i = \dots = \varphi_N \equiv \varphi$ and $H'_1: \varphi_1 < 0, \dots, \varphi_{N_x} < 0$, where $0 < N_x \leq N$. The former (H_1) assumes that the autoregressive parameter is homogeneous for all cross-sectional units, and the latter (H'_1) assumes that some part of the panel units (N_x) are stationary with individual-specific autoregressive coefficients (φ_i). Hence, first, the first-generation PURTs differ depending on which of the two alternatives is being considered in the testing procedure. In this sense, the unit root tests proposed by Harris and Tzavalis (HT) (1999), Breitung (2001), and Levin *et al.* (LLC) (2002) are all based on a more restrictive assumption of homogeneity. In other words, each assumes that all panels have the same common autoregressive parameter for the lagged dependent variable, so that $\varphi_i = \varphi$ for all i in the panel. On the other hand, the tests suggested by Maddala and Wu (MW) (1999), Choi (2001), and Im *et al.* (IPS) (2003) are all motivated by the second alternative

(H_1') that relaxes the assumption of homogeneity and allows for a more realistic assumption of heterogeneous autoregressive coefficients.

Second, these tests make different assumptions about the asymptotic behaviors of the time series (T) and the cross-sectional (N) dimensions of the panel. For instance, the HT (1999) test requires that the number of cross-sectional units should be larger than the time periods in the panel, and hence, their statistic is more appropriate for the studies using relatively large values of N and small values of T , *i.e.*, micro panels. The Fisher (1932)-type test suggested by MW (1999) assumes that the number of panels should be finite when the time dimension asymptotically goes to infinity, but the test suggested by Choi (2001) is suitable for both finite and sequentially infinite numbers of panels. On the other hand, the Lagrange Multiplier (LM) test proposed by Hadri (2000) and, similarly, Breitung's (2001) test are both asymptotically designed for the cases where T and N sequentially go to infinity. In this sense, Hadri (2000) has suggested using the test with large T and moderate N in practice (Hadri, 2000: 149).

Differently, by assuming various asymptotic properties, the LLC (2002) test requires that the time dimension of the panel grows faster than the cross-sectional dimension, $N/T \rightarrow 0$, in cases where there are panel-specific intercepts or time trends. This condition practically implies cases where N is moderate and T is large (Phillips and Moon, 1999). However, this test is also valid for cases where T grows more slowly than N , *i.e.*, for micro panels, but only if individual intercepts or time trends are excluded. However, Levin *et al.* (2002) have argued that their statistics have substantial power for use with various dimensions such as $N = 10$ and $T = 50$ or $N = 25$ and $T = 25$ (Levin *et al.*, 2002: 11-12). On the other hand, the t -bar test proposed by IPS (2003) requires both N and T to be sufficiently large when there is serial correlation in the error terms, but the test also performs well even when T is reasonably fixed, such as $T = 10$ in the absence of serial correlation. However, Baltagi (2013) has argued that the requirements of both the LLC and IPS tests imply that the number of cross-sections should be small enough relative to the number of time periods in the panel (Baltagi, 2013: 282).

Overall, several Monte Carlo experiments for first-generation PURTs have evidently shown that no test dominates the other in terms of power and sample size

(Hlouskova and Wagner, 2006: 113).³⁴ For homogeneous PURTs, for instance, the simulation results of Hlouskova and Wagner (2006) have shown that in cases where the regression equation includes an intercept, the Hadri (2000) test performs very poorly, while the tests proposed by LLC (2002) and Breitung (2001) have the smallest size distortions. On the other hand, for heterogenous panels, MW (1999) reported that the size distortion with the Fisher test is small if a time trend is included in the regressions, where T is large but N is not very large in the panel, while the size distortion of the Fisher test is at the same level as that of the IPS test for medium T and large N (Maddala and Wu, 1999: 644-645). Their results have further indicated that both the IPS and Fisher tests are more powerful than the LLC test in the absence of cross-sectional correlation in the errors.

Moreover, Choi (2001) concluded that the inverse normal Z-test can be applied to both finite and infinite N , and that its size-adjusted power is greater than that of the t -bar test. On the other hand, the simulation results of IPS (2003) have shown that the t -bar test has better small sample properties than the LLC test. Furthermore, they demonstrated that an increase in T is more effective at increasing the power of the t -bar test than a similar increase in N (IPS, 2003: 72). However, given the discussion above, one common deficiency of all first-generation tests is that none of them has control over the problem of cross-sectional correlation in the errors. They all impractically assume that the units in the panel are independent even for the cross-country analysis of macroeconomic series, where individual series are likely to be affected by various common shocks (Moon *et al.*, 2007).

In this context, more recent second-generation PURTs relax this restrictive assumption by allowing for the presence of cross-sectional dependence (CD) in the testing procedure. Some of these tests include Choi (2002), Chang (2002), Phillips and Sul (2003), Bai and Ng (2004), Moon and Perron (2004), and Pesaran (2007). For instance, Chang (2002) models CD by using a nonlinear IV approach for large T and fixed N panels. On the other hand, Choi (2002), Bai and Ng (2004), Moon and Perron (2004), Phillips and Sul (2003), and Pesaran (2007) all model cross-sectional

³⁴ Although the discussion in the study is limited to more recent and commonly used PURTs, there have been other initial efforts to test unit root in panel data, such as Bhargava *et al.* (1982), Boumahdi and Thomas (1991), Breitung and Meyer (1994), and Quah (1994), among others (Baltagi and Kao, 2001).

correlation by using common factor models. In particular, Choi (2002) uses an error-component model to consider CD for the panels with large values of T and N . Phillips and Sul (2003), Bai and Ng (2004), and Moon and Perron (2004) make use of residual factor models, whereas Pesaran (2007) augments the standard D-F regressions with cross-sectional averages of the series. By doing so, he addresses factor effects rather than using a factor estimation approach like others (Kapetanios, 2007: 314; Pesaran, 2007: 266).

Regarding asymptotic properties, all second-generation tests are mostly designed for large values of T and N , while the tests proposed by Moon and Perron (2004) and Bai and Ng (2004) assume that T is relatively larger than N . However, the Pesaran (2007) test is also valid in cases where T and N have the same sizes. The relative performance of several second-generation tests has also been investigated by several Monte Carlo studies. For instance, Gengenbach *et al.* (2009) have shown that Pesaran's (2007) test has better size properties than the test of Moon and Perron (2004). The simulation results of Kapetanios (2007) have also shown that the test proposed by Pesaran (2007) is a reasonable alternative to all other factor-based unit root tests. In his study, Pesaran (2007) also reported that his test statistic has satisfactory size and power for relatively small values of N and T even when there is a high degree of CD and a moderate degree of serial correlation in the residuals. However, if the regression equation contains a linear time trend, the power of Pesaran's (2007) test starts to rise with both N and T , particularly for $T > 30$.

Considering the previous discussion, one can state that each PURT has some statistical shortcomings in terms of size and power properties. Therefore, in this study, one homogeneous and two heterogeneous first-generation PURTs are first applied before the GMM estimations.³⁵ In this sense, a Fisher-type test proposed by MW (1999), the LLC (2002) test, and the IPS (2003) test are used by considering the relative sizes of cross-sectional units and time periods in the sample data.³⁶ However, since first-generation tests suffer from the restrictive assumption of cross-sectional independence, a more widely used second-generation test proposed by Pesaran (2007)

³⁵ The homogeneity assumption, which assumes that all cross-sections have the same autoregressive parameter, is restrictive even for OECD countries.

³⁶ In this study, two panel datasets are employed. For the first sample, $N = 33$ and $T = 39$, while for the second panel, $N = 38$ and $T = 65$.

is also employed to consider cross-sectional dependency in the residuals, given that the sample countries of the study include OECD members. An intercept and a linear time trend are also included in each formulation since the study deals with trending time series, *i.e.*, the levels of macroeconomic aggregates such as real GDP. The details of the tests applied in the study are described below.

MW (1999) has proposed a Fisher-type test that combines the p -values from each unit root test applied to each cross-sectional unit, i . In this sense, if Ω_i is assumed to denote the p -value of the individual-specific unit root test for cross-section i , then the combined test statistic of MW (1999) is given as follows:

$$\bar{\Omega} = -2 \sum_{i=1}^N \log(\Omega_i) \quad (23)$$

The test statistic $\bar{\Omega}$ asymptotically follows a chi-square distribution with $2N$ degrees of freedom in cases where T is infinite and N is finite. For the test statistic $\bar{\Omega}$, the null hypothesis states that each time series is non-stationary, while the heterogeneous alternative assumes that some time series are stationary while the others are not.

On the other hand, Levin *et al.* (2002) have considered the following regression equation to test the unit root in panel data:

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{p_i} \vartheta_{iL} \Delta y_{i,t-L} + \delta_i t + v_{it} \quad (24)$$

where ρ is the autoregressive coefficient, p_i is the lag order, δ_i and t represent the individual effects and time trend, respectively, and v_{it} is the error term. The LLC test is based on the restrictive assumption that all panels have the same autoregressive parameter, so that $\rho_i = \rho$ for all i . In this sense, the null hypothesis that each time series is non-stationary ($H_0: \rho = 0$) is tested against the alternative hypothesis that each time series is stationary ($H_1: \rho \neq 0$). Hence, the test tests whether all cross-sections in the whole panel have or do not have a unit root.

IPS (2003) has suggested an alternative testing procedure that allows for heterogeneous coefficients (φ_i) as in MW (1999). The calculation of their test statistic follows a different process that is based on the average of the individual unit-root test statistics. In other words, to construct the test statistic, IPS (2003) first calculates the

mean of the individual Augmented Dickey-Fuller (ADF) t -statistics for each cross-sectional unit in the panel by running the following regression equation that allows for different orders of serial correlation, such as $v_{it} = \sum_{L=1}^{p_i} \zeta_{iL} v_{i,t-L} + v_{it}$:

$$\Delta y_{it} = \alpha_i + \varphi_i y_{i,t-1} + \sum_{L=1}^{p_i} \vartheta_{iL} \Delta y_{i,t-L} + \delta_i t + v_{it} \quad (25)$$

where φ_i represents heterogeneous coefficients, p_i is the lag number in ADF regressions, α_i denotes individual fixed effects, and t is time trends. Hence, a standardized $t - bar$ statistic based on the mean of the individual ADF statistics is calculated as follows:

$$t - bar = \frac{1}{N} \sum_{i=1}^N t_{\varphi_i} \quad (26)$$

In Eq. (26), N is the size of the panel and t_{φ_i} are the individual t -statistics. The null hypothesis states that each series in the panel contains a unit root, $H_0: \varphi_i = 0$ for all i , and the alternative hypothesis is that at least one of the individual series in the panel is stationary, that is, $H_1: \varphi_i < 0$ for $i = 1, 2, \dots, N_x \leq N$ and $H'_1: \varphi_i = 0$ for $i = N_x + 1, \dots, N$.

Lastly, Pesaran (2007) has suggested a Cross-Sectionally Augmented ADF (CADF) test to address CD in error terms. In his test, Pesaran (2007) considered three alternative models of serial correlation, all of which led to the same ADF regression but with different error specifications and parameter heterogeneity.³⁷ In general, the p -th order augmented CADF regression that allows for a possible CD and serial correlation in error terms for an $AR(p)$ process has the following form:

$$\Delta y_{it} = \alpha_i + \varphi_i y_{i,t-1} + a_i \bar{y}_{t-1} + \sum_{L=0}^p c_{iL} \Delta \bar{y}_{t-L} + \sum_{L=1}^p d_{iL} \Delta y_{i,t-L} + \delta_i t + v_{it} \quad (27)$$

where α_i , t , and p denote individual effects, a linear trend, and a lag order, respectively. In Eq. (27), the error term has a single-factor structure such as $v_{it} =$

³⁷ Please refer to Pesaran (2007) Section 5 for details.

$\gamma_i f_t + v_{it}$, where f_t is the unobserved common effect, and v_{it} is the idiosyncratic error. The common factor f_t is proxied by $\bar{y}_t = N^{-1} \sum_{i=1}^N y_{it}$ and the lagged values of $\bar{y}_t$, which denotes the cross-section mean of y_{it} . To obtain his *CIPS* statistic, the following averaging procedure is followed by using t -statistics of the estimate on φ_i ($CADF_i$), which are obtained by running CADF regression in Eq. (27) for each i .

$$CIPS(N, T) = t - bar = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \quad (28)$$

where $t_i(N, T)$ is the CADF statistic for unit i derived from the t -ratio of the estimate on φ_i in Eq. (27). Similar to other first-generation tests, the null hypothesis assumes the existence of a unit root, $H_0: \varphi_i = 0$ for all i , and the heterogeneous alternative assumes some fraction of the individual processes (N_x/N) is stationary, such as $H_1: \varphi_i < 0$ for $i = 1, 2, \dots, N_x$ and $H'_1: \varphi_i = 0$ for $i = N_x + 1, \dots, N$.

1.4.1.2. A Dynamic Panel Data Estimator: The System GMM

The majority of the empirical growth literature has focused on the estimation of cross-sectional versions of convergence regressions, à la Barro (1991) and Mankiw *et al.* (1992), although the main suggestion of neoclassical growth is the convergence within a country rather than across countries. The main motivation of these studies has been to test the theory by making practical generalizations for policy about the effects of different variables on long-run economic growth, which is difficult to tackle by focusing on a single country or a small number of countries. To this end, these studies have mostly used large cross-country datasets for a number of N countries and a number of T time periods. However, the empirics of these studies differ depending on their estimation methods and, hence, on their choice of the length of the averaged time interval (τ) lying between two observations of the income variable at two different time points, namely y_{it} and $y_{i,t-1}$, as given in the left-hand side (LHS) of Eq. (21a). For a long time, the earliest studies in this literature used cross-sectional methods by using averaged data over τ -year periods by implicitly assuming $\tau = T$. As a result, they employed a single cross-sectional regression with N countries, mostly fixing the

initial income ($y_{i,t-1}$) around 1960. For instance, Mankiw *et al.* (1992) assumed that $\tau = 26 = T$ by using a sample period over the years between 1960 and 1985, *i.e.*, $t_1 = 1960$ and $t_2 = 1985$, according to the formulation of Islam (1995). However, applying this framework leads to the omission of unobservable factors across countries, which may include differences in the initial level of technology, resource endowments, climate, institutional environment, culture, political regime, and geography, among others. All these factors about the unobservable sources of economic growth may be best explained by Abramowitz (1956) as '*the measure of ignorance*' or '*the big residual*' that broadly defines territorial differences in TFP (Abramowitz, 1956, 1993).

One remedy for unheeded unobserved factors in convergence regressions has been to expand the convergence regressions with more variables related to income growth, which also forms the basis for well-known Barro (1991) regressions. The inclusion of additional variables in these regressions is considered a solution for relaxing the assumption of random TFP differences (Durlauf *et al.*, 2005: 579). However, this framework has not been enough to solve the problems, as the estimates of convergence rates have continued to remain severely biased. Another limitation of using this framework has been the assumption of constancy for growth variables and parameters. That is, a single cross-section spanning the entire sample period implicitly assumes the savings rate, the population growth rate, and the evolution of the unobservable factors to be constant for the entire sample period for each country. In this manner, one common response to this restrictive assumption about parameter constancy has come from drawing on more time variation in growth variables by applying panel data methodologies. Hence, these cross-sectional studies were first extended to panel data studies by transforming the single convergence equations into a panel framework in order to overcome the limitations of cross-sectional data and provide more realistic growth estimates.

Compared to their cross-sectional counterparts, panel studies use cross-country data expressed in non-overlapping time points over some τ -year intervals. In this way, the studies that use this framework employ a panel of N countries and T/τ time points by allowing for a limited amount of time variation in the growth variables. Initially, regular panel OLS and Within Group (WG) estimators became widely used in the

literature to test the convergence hypothesis, although these methods presented a set of problems on their own. In other words, these estimators are not suitable for the dynamic nature of the convergence equation since strict exogeneity of the regressors no longer holds if the lagged value of the dependent variable appears as an explanatory variable, particularly in cases where the panel is small. For instance, the pooled OLS estimator leads to biased and inconsistent estimates in a dynamic model due to the correlation between the lagged dependent variable and the error term containing unobserved effects (Hsiao, 2014: 85-86). As a result, while this framework allows the parameters for population growth and savings rates to become constant over shorter time periods τ rather than over the entire sample period T , the OLS level estimator continues to suffer from heterogeneity bias due to omitting unobserved individual effects. This omitted variable bias also indicates that the OLS levels estimator is biased upwards in a dynamic panel framework, which further biases the estimated rates of income convergence.

The WG estimator, on the other hand, attempts to eliminate this inconsistency caused by the pooled estimator by allowing the initial productivity levels to become heterogeneous across countries and the productivity changes that are common to all countries to be varied over some specific time points. However, the transformation process required to remove unobserved effects induces this estimator to be inconsistent due to the Nickell (1981) bias. In other words, WG estimation results in a dynamic panel bias caused by having to remove the unobserved individual effects from each observation, which in turn creates a correlation between the lagged level of the dependent variable and the error term when the time dimension is fixed (Nickell, 1981). Furthermore, for short panels, the elimination process of unobserved heterogeneity produces a downwardly biased estimate for the lagged level of the dependent variable ($y_{i,t-1}$). Therefore, although explicit modeling of unobserved heterogeneity is required in many growth research settings, most of the employed estimators strictly require that all regressors be exogenous.³⁸ This assumption is violated in previous growth studies, and this violation results in an endogeneity bias,

³⁸ Although its use is limited in growth studies, the Between Group estimator also results in an upwardly biased estimate of the coefficient on the lagged dependent variable in a dynamic and short panel case (Mátyás and Sevestre, 2008: 253).

particularly due to the inclusion of a lagged dependent variable among other potential sources of endogeneity. This inconsistency stemming from omitted variables' bias disappears for the WG estimator for panels with large T , but the OLS estimator remains inconsistent even when $T \rightarrow \infty$.

In this sense, the ability of first differencing has appeared as one prominent practice to eliminate the bias caused by static panel estimators while paving the way for the development of dynamic panel estimators. The main difference between these approaches lies in the estimator, such that the dynamic estimator is argued to overcome the issue of endogeneity even in short panel data models. The initial dynamic approaches have started to eliminate unobserved heterogeneity by first differencing and employing the lagged levels of the series as instruments for the predetermined and endogenous variables in first differences (Blundell *et al.*, 2001: 54). For instance, Anderson and Hsiao (1981, 1982) have proposed an IV approach and used a 2SLS estimator with instruments that include lagged predetermined variables in levels. However, Holtz-Eakin *et al.* (1988) have pointed out the use of the GMM proposed by Hansen (1982) to obtain asymptotically more efficient estimators for dynamic panel models, which further forms the basis for the difference GMM proposed by Arellano and Bond (1991). Although these estimators offer a partial solution to the problem of endogeneity through the use of instruments, it has been argued that they suffer from the issue that there is no correlation between instruments and explanatory variables of the model, which is further known as the problem of weak instruments (Mátyás and Sevestre, 2008: 262).

In this context, several studies have shown that these estimators exhibit poor performance in some cases where individual series are highly persistent, instruments are weak, and the time dimension is fixed (Blundell and Bond, 1998; Blundell *et al.*, 2001). Furthermore, Ahn and Schmidt (1995, 1997) have argued that these previous estimators suffer from a serious inefficiency since they do not employ all existing moment restrictions and suggest a nonlinear GMM by using extra moment conditions. Arellano and Bover (1995) expanded on these works by proposing a linear GMM estimator based on orthogonal deviations to eliminate unobserved effects rather than a first-difference transformation. The advantage of this transformation is that it does not cause any serial correlation problems in the residuals of the transformed model, which

is the case for the first-difference one. This estimator suggested by Arellano and Bover (1995) has been further improved by Blundell and Bond (1998) by using initial conditions to obtain extra moment conditions. The use of these additional conditions significantly improves the precision of first-difference estimators, especially for studies using short panels and highly persistent series (Blundell *et al.*, 2001; Bond *et al.*, 2001). Thus, Blundell and Bond (1998) have proposed this extended GMM estimator that includes a system of both first difference and level equations. This extended estimator (i) combines the restrictions demonstrated by Arellano and Bover (1995) with stationary restrictions on initial conditions, (ii) exploits nonlinear conditions suggested by Ahn and Schmidt (1995, 1997), and (iii) uses both the lagged differences and levels of the dependent variable as instruments (Baltagi and Kao, 2001; Blundell and Bond, 1998; Blundell *et al.*, 2001).

Therefore, the system GMM estimator has begun to be highly suggested for dynamic panel data studies, as the estimator has considerable efficiency gains over OLS levels, WG, and first-difference estimators given that they all suffer from serious finite sample bias even when the number of cross-sectional units in the panel is large. For instance, the OLS level estimator overestimates the true value of the coefficient on the lagged dependent variable, while the WG estimator underestimates it. Thus, the system GMM estimate of the lagged dependent variable is considered to lie between the approximate upper and lower limits provided by panel OLS and WG estimates, respectively (Bond, 2002; Bond *et al.*, 2001; Hoeffler, 2002). On the other hand, although the difference and system GMM estimators are both designed for the same cases, the latter is more efficient than the former, which (i) is subject to serious finite sample bias if sample series are near being random walks and (ii) its estimate on the lagged dependent variable is downwardly biased towards the WG estimator if there are poor instruments and a small-time dimension in the panel (Blundell and Bond, 2000; Bond, 2002; Bond *et al.*, 2001). However, the system GMM estimator (i) allows the inclusion of more instruments, (ii) reduces finite sample bias, and (iii) improves the precision even when the panel is short and individual panel series are highly persistent (Blundell and Bond, 2000; Bond *et al.*, 2001; Roodman, 2009a).

The empirical literature on economic growth has also benefited from the advances in econometric theory to obtain more precise estimates in testing the

convergence argument. Hence, single cross-country convergence regressions followed by Baumol (1986), Barro (1991), Mankiw *et al.* (1992), Barro and Sala-i-Martin (1992b), and King and Levine (1993) have been first replaced by panel data approaches in the studies of Barro and Lee (1993, 1994), Barro (1996a), and Sala-i-Martin (1996a, 1996b) with an effort to partly eliminate the issue of endogeneity while still allowing the existence of correlated individual effects. In this sense, the studies by Knight *et al.* (1993), Loayza (1994), and Islam (1995) have provided a significant shift in the estimation strategy by eliminating this correlation problem through applying Chamberlain's (1984) approach. This shift in empirical strategy allows (i) for more time variation in the data and (ii) to partially relax unrealistic assumptions that each country has an identical initial level of productivity and that productivity growth is constant over time.

Hence, this approach allows for the correction of omitted variable bias at the expense of the problem of endogeneity. In this context, Caselli *et al.* (1996) were the first to introduce the difference GMM estimator into the growth literature to simultaneously deal with the problem of endogeneity and correlated country effects. However, Bond *et al.* (2001) have criticized their study by arguing that the differenced estimator of the coefficient on initial income is seriously biased due to the presence of poor instruments. In their study, Bond *et al.* (2001) reestimated the standard and human capital-augmented Solow growth models by using difference and system GMM estimators for the same sample used by Caselli *et al.* (1996). Their findings have indicated that the system GMM estimator provides more efficient and consistent estimates for empirical growth work than any other coeval estimator. Since then, the system GMM has become prevalent in growth studies and has been followed in the studies of Levine *et al.* (2000), Hoeffler (2002), and Ding and Knight (2009, 2011), among others.

Following the above discussion, the system GMM approach is applied in this study to avoid the drawbacks of other conventional estimators used in previous studies. The preceding studies in the related literature, which have estimated an income convergence equation based on a theory-driven inclusion of human capital in the form of health, have mostly relied on the use of cross-sectional data approaches (Knowles and Owen, 1995, 1997; Rivera and Currais, 1999a; Webber, 2002) or static panel data

frameworks (Heshmati, 2001; Li and Huang, 2009; McDonald and Roberts, 2002; Rivera and Currais, 1999b). In their empirical analyses, some of these studies have tried to address the issue of potential endogeneity resulting from simultaneity bias. To avoid these simultaneity concerns, some of them have added instrumental variables to their convergence regressions. These instrumental variables mostly include the lagged values of potential endogenous regressors such as health and education (Li and Huang, 2009; Knowles and Owen, 1995) or the base-period values of these endogenous variables (Webber, 2002). However, one problem with this strategy is that these instrumental variables are still correlated with the unobserved features of the sample countries and remain in the estimated residuals.

On the other hand, others have made use of various determinants of health that are external to the theoretical model and considered exogenous with respect to income growth, *e.g.*, the number of physicians and hospital beds, alcohol consumption, the number of beds in inpatient care, physician contacts per person, and the share of the population covered by public health care (Knowles and Owen, 1997; Rivera and Currais, 1999a, 1999b). However, this time, their exogeneity has always remained suspicious and unclear. Hence, whilst some of these studies have tried to find a natural solution to the problem of endogeneity, others have employed static panel estimators with country-specific effects to address unobserved heterogeneity but at the expense of endogeneity (Heshmati, 2001; Li and Huang, 2009; McDonald and Roberts, 2002). However, none of them has become sufficient to simultaneously deal with the statistical shortcomings faced by empirical growth research discussed above.

In this sense, using system GMM for the empirical test of the dynamic convergence equation theoretically derived in this study provides more robust and unbiased estimates than other traditional approaches used in previous studies. This estimator, in particular, allows for the elimination of the endogeneity problem by instrumenting any endogenous variable with other variables that are thought to be uncorrelated with the sample countries' unobserved heterogeneous features. In this way, from an econometric standpoint, the estimator simultaneously allows for the inclusion of both individual and period fixed effects and endogenous regressors into the regression equation. From the standpoint of empirical growth, this approach allows for the consideration of (i) differences in the starting levels of technology across

countries, (ii) common temporal differences in technological change across countries, and (iii) potential endogeneity arising not only from unobservable omitted variables but also from the simultaneity of output and other growth variables. This last point deserves more attention and can be expressed more specifically as follows:

In convergence regressions, some of the Solow-growth and other variables are actually determined simultaneously with the level of income, which leads to the existence of a dynamic endogeneity between them in some cases. For instance, a dynamic feedback mechanism may exist between previous shocks to income and current investment in addition to the simultaneity between currently occurring shocks to income and present investment (Hoeffler, 2002: 140). Similarly, for the case in this study, not only do increases in the share of the healthy labor force or better health status stimulate output production, but higher output growth also raises the share of the healthy labor force and improves the health status of the workforce. Furthermore, the relationship between these two variables may be subject to dynamic endogeneity in such a way that the past values of output may affect the current or past investments in health, which in turn may increase the current health level of the workforce.^{39,40}

Hence, the system GMM estimator helps to deal with any endogeneity issue encountered in the estimation process by instrumenting all endogenous variables with other variables that are regarded as unrelated with unobserved effects. Additionally, the estimator ensures the consistency of the necessary restrictions on initial conditions within the standard Solow growth framework even for highly persistent series (Blundell and Bond, 2000; Bond, 2002; Bond *et al.*, 2001). In short, by combining low bias and high efficiency in the case of short panels, the estimator provides a reasonable alternative for this research, which examines the out-of-steady-state behavior of a Solovian economy with healthy workers and a generous government.

³⁹ Many studies in the literature that have shown that not only do health improvements raise income (Arora, 2001; Bloom and Canning, 2000; Bloom *et al.*, 2004, 2018; Hartwig, 2010; Mayer, 2001a, 2001b; Swift, 2011; Weil, 2007), but increases in income also significantly improve the health condition of the population (Cervantes *et al.*, 2019; Cutler *et al.*, 2006; Dalgaard and Strulik, 2014; Frijters *et al.*, 2005; Meer *et al.*, 2003; Morand, 2004; Preston, 1975, 1980; Pritchett and Summers, 1996). This interrelationship between income and health is one of the main reasons for using the system GMM estimator in this study.

⁴⁰ Income and total health expenditures have also a bidirectional relationship (Aslan *et al.*, 2016; Erdil and Yetkiner, 2009; Heshmati, 2001; Rivera and Currais, 2003).

1.4.2. Data

This chapter uses a panel dataset for OECD countries with a large time-series dimension that may vary across countries, *i.e.*, an unbalanced panel.⁴¹ Conventionally, the study relies on the Penn World Table⁴², also formerly known as the Summers-Heston dataset, to obtain the data on Solow-growth variables, including real GDP per worker, the savings rate of physical capital, and the effective depreciation rate. As this chapter aims to explore the growth implications of health through the labor force, the output-side definition of real GDP is used in the analysis, which provides a measure of relative productive capacity across countries and over time instead of living standards (Feenstra *et al.*, 2015: 3154). The output measure is also based on chained purchasing power parities (PPPs), which are essential for making accurate cross-country comparisons of national incomes.

Hence, in the study, real GDP per worker (y_{it}) is measured as output-side real GDP (in millions of 2017 US dollars) divided by the total number of people engaged in a productive activity (in millions). Instead of per capita definitions, using per worker variables is more appropriate for this study, both (i) to focus exactly on the population contributing to production and (ii) to eliminate the sensitivity of the findings to the differences in the shares of countries' dependent populations.⁴³ Furthermore, excluding the non-working age population does not lead to a possible bias in the estimations since employment under the minimum age is generally low in high-income countries (Webber, 2002).

The savings rate (s_{Kit}) is measured as the rate of gross capital formation at current PPPs. The annual growth rate of the labor force (n_{it}) is calculated from the data on the number of people engaged, which includes ages 15 and over. Different

⁴¹ In this chapter, the country choice is limited to OECD countries since the data on absence from work due to illness is only available for this country group. However, by doing so, the sample of the study was restricted to countries that are structurally similar in a way that they may have the same steady-state features.

⁴² PWT version 10.0 was used in the study, which was revised in June 2021.

⁴³ The average share of the dependent (elderly + young) population in the total working-age population in OECD countries is generally high. It was 63.3% in 1960, 57.3% in 1981, and 54.1% in 2019 (WB, 2022). Hence, the population growth rate has been lower than the growth rate of the workforce. For 38 OECD countries, the average population and workforce growth rates were 0.64% and 1.01% for the 1981-2019 period, while these rates were 0.87% and 1.12% over the 1955-2019 period (the author's calculations based on PWT data).

from previous studies, the study further allows the depreciation rate (δ_{it}) to vary across countries and time instead of assuming a constant rate of three percent. Hence, the augmented rate of workforce growth, or the effective depreciation rate ($n_{it} + \omega + \delta_{it}$), is obtained as the sum of the workforce growth rate, the depreciation rate, and the rate of technological progress (ω) that is assumed to be constant at 0.02 as in Mankiw *et al.* (1992).⁴⁴

Deviating from related literature, this study uses several health indicators that could represent the healthy share or the health status of the labor force instead of using conventional measures of health, including longevity at birth and infant or child mortality rates. However, it is always hard to find a suitable proxy for health indicators due to the lack of data on more refined measures of health. Therefore, this study employs a few health measures related to the working population of a country due to the absence of a suitable proxy that shows the exact proportion of healthy workers engaged in production or the total morbidity rate. To this end, first, the study calculates and uses the share of healthy working time in the total working period as a proxy for the healthy share of the labor force defined in the theoretical model (ϕ_{Hit}).

In this context, the data on absence from work due to illness was obtained from the OECD health statistics database to proxy for the absent hours of the unhealthy labor force, $L_{UH_{it}}$. This data (i) refers to the number of working days lost per year per currently employed person (OECD, 2022b), and (ii) allows to ensure that only non-working time due to health problems is taken into account rather than other reasons including maternity leave, public holidays, labor disputes, *etc.*⁴⁵ As a second step, each data point was converted to hour terms by multiplying by 24 and subtracted from normal annual working hours—a proxy for L_{it} —that were obtained from normal weekly hours limits provided by the International Labor Organization (ILO) (ILO, 2013: 20-30).⁴⁶ As a result, annual healthy working hours have been obtained for each

⁴⁴ Mankiw *et al.* (1992) have used 0.05 as the value of the sum of the depreciation rate and the technology growth rate, while Caselli *et al.* (1996) have used an alternative value of 0.07 and reported that there is not any substantial difference in their results.

⁴⁵ A few databases, including the OECD Labor Statistics and ILO Statistics on Working Time, publish the data on average annual hours actually worked by employees. However, these figures include time spent away from work for several reasons in addition to health, such as maternity, paid leave, injury, training, sickness, meal breaks, a strike, and inclement weather, among others.

⁴⁶ The PWT also provides data on the average annual hours worked by persons engaged, but the data includes non-working time due to any reason, including ill health, as do the OECD and ILO data.

country to be used in the empirical analysis as a proxy for healthy workers, $L_{Hit} = L_{it} - L_{UH_{it}}$. Furthermore, because the intensive form of the production function in Eq. (2) actually includes the share of healthy workers in the total workforce, the share of annual healthy working hours (ϕ_{Hit}) for each country has been calculated by dividing annual healthy working hours (L_{Hit}) by normal annual working hours (L_{it}), $\phi_{Hit} \equiv \frac{L_{Hit}}{L_{it}}$ and $0 < \phi_{Hit} < 1$.⁴⁷

In the estimations, two different but related health measures proxying for the share of healthy working days of the labor force are employed for robustness checks: (i) the share of annual healthy working hours in total hours (ϕ_{Hit}), and (ii) the inverse of the absent days from work due to illness ($1/L_{UH_{it}}$), which is a reasonable inverse proxy for absent working days due to ill health. That is, an increase in this ratio indicates an increase in the number of healthy working days. In brief, two measures proxy the healthy time spent at work per worker per year and are expected to positively affect per-worker output growth while increasing the estimated rates of output convergence.

Secondly, since each proxy has some shortcomings in reflecting the exact variables defined in the theoretical model, the study further includes age-specific measures of life expectancy and adult mortality to proxy for the health status of the working-age population. Life expectancy at birth and infant or child mortality rates are among the most frequently used indicators in growth studies to measure health status (Barro, 1996a; Barro and Sala-i-Martin, 2004; Bloom *et al.*, 2001; Caselli *et al.*, 1996; Gyimah-Brempong and Wilson, 2004; Hamoudi and Sachs, 1999; Knowles and Owen, 1995, 1997; McDonald and Roberts, 2002). However, the use of these indicators is more appropriate for population-level studies. For instance, life expectancy at birth provides the mean of mortality rates for all age groups and is highly sensitive to infant and child mortality rates, which are irrelevant to productivity (Arora, 2001; Jamison

Therefore, the legal normal weekly hours' limits provided by the ILO (2013) were used in the study, as there is no detailed data showing the exact days worked in a year for each country and clustering the days off according to their reasons. This data was further multiplied by 52 to proxy for the total annual hours supplied by the workers of each country. Hence, by doing so, the study excludes the differences in the countries' national and religious holidays, among other reasons for days off.

⁴⁷ It is the same as using the following formula: $\phi_{Hit} \equiv 1 - \frac{L_{UH_{it}}}{L_{it}}$.

et al., 2005). Instead, life expectancy at higher ages directly focuses on the health status of the working-age population and hence provides a more appropriate measure to consider the productivity implications of workforce health. Similarly, using adult mortality rates helps better understand the health status of the economically most productive age group.⁴⁸ Furthermore, for high-income OECD countries, the burden of noncommunicable diseases (NCDs) and aging is relatively high compared to that of infant mortality (Geppert *et al.*, 2019; OECD, 2021: 86, 250). Therefore, it is more relevant to refer to the adult mortality patterns to measure the current health status of both the productive and total populations in these member countries.

Accordingly, life expectancy at specific ages, including the ages of 15, 20, 30, 40, 50, and 60, is used in the analyses to consider the health status of the most productive age span in a country. Life expectancy at a given age refers to the mean number of prospective years that the individuals at that age expect to remain alive and is linked to the rates of mortality for a given period in their remaining years of life. In other words, life expectancy at a specific age sums up the information on the overall mortality level of the population over a given age and excludes the information below that specific age. Moreover, adult mortality rates between ages 15 and 60 are used to capture the probability of death in the working-age population. This measure is calculated as the number of deaths under the age of 60 divided by 1,000 people alive at the age of 15. In other words, it gives the probability that a 15-year-old will die before age 60. Although the working-age population covers the population aged 15 to 64, both variables include the age group from 15 to 60 due to data availability.

As a result, the measures of life expectancy and mortality used in this study cover new labor-market entrants aged 15 and 20, workers in their prime working periods aged 30, 40, and 50, and those approaching the end of their working lives aged 60. Life expectancy at specific ages is expected to have a positive effect on per-worker output growth, whereas adult mortality is expected to have a negative effect on growth. Furthermore, both measures are expected to increase the estimated rates of output convergence. Data on life expectancy at specific ages (in years)

⁴⁸ Previously, several Barro-type studies on growth have applied age-specific adult mortality rates for men (Jamison *et al.*, 2005) and ASRs at different age intervals (Bhargava *et al.*, 2001; Mayer, 2001a). Their results have shown that these indicators are better predictors of growth than the other standard indicators of health, such as life expectancy at birth and infant mortality.

($L15_{it}$, $L20_{it}$, $L30_{it}$, $L40_{it}$, $L50_{it}$, and $L60_{it}$) as well as adult mortality rates (MRT_{it}) were obtained from the World Population Prospects database of the UN (2019). Data for the two indicators are provided in five-year intervals from 1950 to 2020.

As the theoretical model is further expanded to include the effect of government expenditures, the data on income tax, government expenditures, and tax revenues are alternately used in the analyses to proxy for the rate of the income tax, $\tau_{it} = \frac{G_{it}}{Y_{it}} = \frac{TAXR_{it}}{Y_{it}}$. Hence, the income tax rate is proxied by the taxes on income, profits, and capital gains as a percentage of total taxes (τ_{it}), the share of government expenditures is measured as the general government's final consumption expenditures as a percentage of GDP ($gov_{it} = \frac{G_{it}}{Y_{it}}$), and the share of tax revenues refers to tax revenue as a percentage of GDP ($taxr_{it} = \frac{TAXR_{it}}{Y_{it}}$). The shortage of the income tax from one in Eq. (21a) ($(1 - \tau_{it})$) is also calculated by using the data on taxes on income, profits, and capital gains as a percentage of total taxes. All data was obtained from the World Development Indicators (WDI) database of the WB (2022). The study also includes two control variables, including human capital in the form of education (HC_{it}) and trade openness ($OPEN_{it}$), to partly eliminate omitted variable bias in the analyses. The data on human capital is measured as an index that includes schooling years and returns to education, and trade openness is calculated as the percentage sum of the shares of merchandise exports and imports at current PPPs. Both series were drawn from the PWT (Feenstra *et al.*, 2015).

As a result, due to the availability of data on health measures, two separate panel datasets are employed in the analyses. The first contains data on Solow-growth variables (y_{it} , $s_{K_{it}}$, n_{it} , δ_{it}), healthy working hours ($\phi_{H_{it}}$ and $1/L_{UH_{it}}$), government indicators ($(1 - \tau_{it})$, τ_{it} , gov_{it} , and $taxr_{it}$), and control variables (HC_{it} and $OPEN_{it}$) for 33 OECD countries over a 39-year period, from 1981 to 2019.⁴⁹ The second dataset contains data on Solow variables (y_{it} , $s_{K_{it}}$, n_{it} , δ_{it}), age-specific life expectancy and

⁴⁹ The sample countries are Australia, Austria, Belgium, Canada, Chile, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Hence, five member countries—Colombia, Iceland, Italy, Japan, and New Zealand—were excluded from the sample due to a lack of data.

mortality measures ($L15_{it}$, $L20_{it}$, $L30_{it}$, $L40_{it}$, $L50_{it}$, $L60_{it}$ and MRT_{it}), government indicators ($(1 - \tau_{it})$ and τ_{it}), and control variables (HC_{it} and $OPEN_{it}$) for 38 OECD countries from 1955 to 2019.⁵⁰ The variables gov_{it} and $taxr_{it}$ are not further included in the estimations of the second sample. Panels A and B of Table 1 below present the descriptive statistics of the annual data for the two sample sets, respectively. Some salient features of the data are as follows:

Table 1: Descriptive Statistics

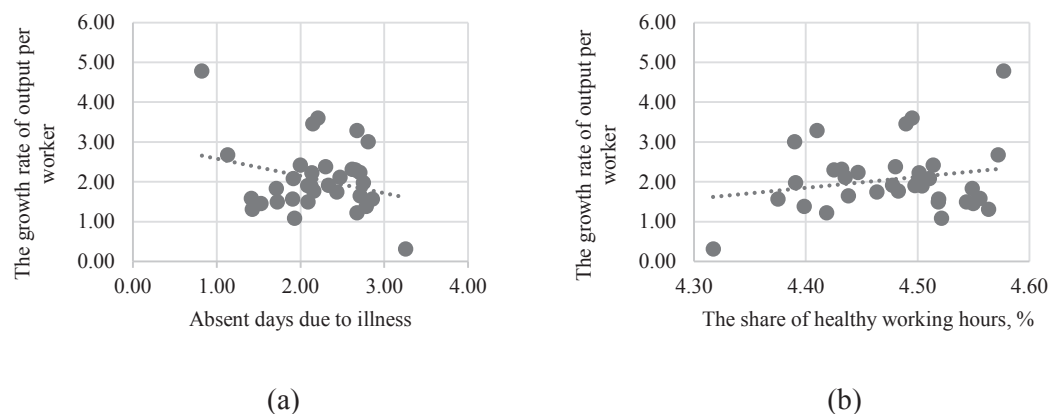
	<i>Mean</i>	<i>Median</i>	<i>Std. Dev.</i>	<i>Min.</i>	<i>Max.</i>
PANEL A					
<i>Sample Set 1: 1981-2019</i>					
y_{it} (2017, US\$)	66259.89	63755.55	28174.20	14373.84	221661.20
$s_{K_{it}}$ (%)	25.67	25.66	6.01	8.16	56.99
n_{it} (%)	0.98	1.16	2.20	-13.98	7.85
δ_{it} (%)	3.74	3.69	0.66	2.07	7.12
$\phi_{H_{it}}$ (hours)	0.88	0.89	0.06	0.71	0.99
$1/L_{UH_{it}}$ (days)	0.12	0.11	0.08	0.04	0.83
$L_{UH_{it}}$ (days)	10.76	9.40	5.27	1.20	27.90
$L_{UH_{it}}$ (hours)	258.14	225.60	126.52	28.80	669.60
$(1 - \tau_{it})$ (%)	57.35	59.19	15.76	7.41	90.45
τ_{it} (%)	42.65	40.81	15.76	9.55	92.59
$taxr_{it}$ (%)	19.34	20.16	5.83	7.30	36.50
gov_{it} (%)	18.71	17.82	6.30	6.60	46.98
HC_{it} (index)	3.05	3.12	0.46	1.51	3.89
$OPEN_{it}$ (%)	-3.50	-3.25	11.15	-59.22	39.83
PANEL B					
<i>Sample Set 2: 1955-2019</i>					
y_{it} (2017, US\$)	53839.62	49635.12	28330.43	4224.84	221661.20
$s_{K_{it}}$ (%)	26.23	25.83	6.91	8.09	56.99
n_{it} (%)	1.12	1.14	2.00	-13.98	7.85
δ_{it} (%)	3.59	3.51	0.71	2.07	7.12
$L15_{it}$ (years)	60.72	60.43	3.92	47.21	69.70
$L20_{it}$ (years)	55.92	55.60	3.83	42.93	64.77
$L30_{it}$ (years)	46.46	46.07	3.62	34.77	55.00
$L40_{it}$ (years)	37.11	36.70	3.37	26.73	45.27
$L50_{it}$ (years)	28.16	27.71	3.04	19.03	35.79
$L60_{it}$ (years)	19.97	19.56	2.61	11.74	26.73
MRT_{it} (deaths)	133.84	130.00	52.65	47.00	337.00
$(1 - \tau_{it})$ (%)	57.00	58.80	16.08	7.41	90.72
τ_{it} (%)	43.00	41.20	16.08	9.28	92.59
HC_{it} (index)	2.79	2.85	0.57	1.18	3.89
$OPEN_{it}$ (%)	-4.00	-2.89	9.65	-62.64	39.83

Note: Std. Dev., Min., and Max. refer to the standard deviation, the minimum, and the maximum, respectively.

⁵⁰ The sample countries include Australia, Austria, Belgium, Canada, Chile, Czechia, Colombia, Costa Rica, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

For the 1981-2019 period, the average value of per-worker output in 33 OECD countries was approximately 66,260 million dollars, while this average was 53,840 million dollars over the 1955-2019 period if 38 members are considered.⁵¹ The mean investment rates were similar in the two samples, with a rate of approximately 26%, and these rates ranged from the minimum of 8% to the maximum of 57%. In terms of illness-related absence, the mean number of unhealthy days was about 11 days per worker in 33 OECD members over the 1981-2019 period. Over this period, Korea had the lowest number of absent days with 1.2 days per worker in 2019, whereas Mexico had the highest number of absent days with 27.9 per worker in 2016. As for the health measures in the second sample given in Panel B, the average life expectancy at age 15 was about 61 years in 38 OECD countries, while this average decreased to 20 years if the life expectancy at age 60 is considered in the 1955-2019 period. Over the sample period, Japan had the highest expected years at all ages from 15 to 60, while Korea had the lowest ones. Finally, for adult mortality rates between ages 15 and 60, the average adult mortality among 38 OECD countries was about 134 deaths over a 65-year period, with a variation of about 53 deaths among the sample countries.

Figure 1: Scatter Plots of the Growth Rate of Output per Worker versus Sickness Absenteeism



Source: The calculations of the author. The raw data were from the OECD (2022b) and PWT 10.0 (Feenstra *et al.*, 2015).

Figure 1 plots the relationship between the growth rate of output per worker and health proxies for the first sample set used in the study. In each part, the vertical

⁵¹ According to the WB's country classification by income, all OECD countries are high-income countries, except for Colombia, Costa Rica, Mexico, and Turkey, which are in the upper-middle-income class.

axis gives the average percentage growth rate of the log of output per worker for 33 OECD countries over the 1981-2019 period. On the other hand, the horizontal axis shows the average of the log of absent days in part (a) and the log of the percentage share of healthy annual working hours in part (b). Part (a) demonstrates that for 33 OECD countries, there is a negative relationship between per-worker output growth and the number of absent days per worker due to illness ($\ln(L_{UH_{it}})$), but this relationship becomes positive in Part (b) when the share of healthy working hours in total working hours ($\ln(\phi_{H_{it}})$) is considered.

Once and for all, the study opts for non-overlapping time intervals widely used in the empirical convergence literature to minimize business cycle effects, which inevitably dominate the short-run variation in growth rates. However, there is no consensus on the determination of the time intervals, even though it is difficult to select an appropriate one given the presence of cyclical effects. For instance, Ding and Knight (2009) have argued that three-year averages are more sensitive to temporary factors associated with business cycle fluctuations. On the other hand, it is more likely to obtain more time-series variation with a shorter interval compared to a longer one (Ding and Knight, 2011; Islam, 1995). The data in this study were averaged by using non-overlapping 5-year time intervals, as in the studies of Islam (1995), Caselli *et al.* (1996), and Bond *et al.* (2001). Hence, the two final samples included in the estimations contain (i) 33 OECD member countries and a total of 8 time points observed over 5-year intervals over the 1981-2019 period (the first sample) and (ii) 38 OECD countries and 13 time points observed quinquennially over the 1955-2019 period (the second sample). All variables are used in their natural log forms in the analyses.

1.4.3. Findings

Several PURTs are employed to identify the stationarity properties of the annual series for the two sample sets used in the analyses. To this end, three first-generation tests proposed by MW (1999), LLC (2002), and IPS (2003), as well as a second-generation test suggested by Pesaran (2007), are applied to obtain more precise results since each test has some shortcomings. Tables 2 and 3 report the results of

PURTs for the natural logarithms of the annual series in the first and second samples, respectively. Panels A and B of each table show the test results for the log levels and for the first differences in logs of the sample series, respectively. For the first sample in Table 2, the results in Panel A show that some sample series, including lagged real output per worker, the savings rate, health proxies, human capital, and the share of government expenditures, suffer from unit root according to the results of the LLC and IPS tests. However, the results of the Fisher-ADF and cross-sectionally augmented IPS (CIPS) tests show that all series are stationary in their log levels.

Furthermore, in Panel B, the results of both first- and second-generation tests show that all series are described by stationary processes. Taken as a whole, the results in Table 2 show that the sample series in the study do not suffer from unit root issues.^{52,53} For the second sample, the test results are provided in Table 3. The results of first-generation tests in Panel A show that the null hypothesis of non-stationarity is significantly rejected for all series in the sample, except for the log levels of human capital according to the results of the IPS and ADF tests.⁵⁴ However, under the assumption of CD, the CIPS statistic indicates that the null of unit root is rejected for the log-levels of all series. The results of Panel B further show that the log series can be characterized as stationary processes in their first differences. Overall, the series in the second sample of the study are also free of unit root.

Table 2: Results of PURTs - Sample Set 1

	<i>FISHER</i> <i>ADF</i>	<i>LLC</i> <i>Adjusted t*</i>	<i>IPS</i> <i>W-t-stat.</i>	<i>PESARAN</i> <i>CIPS</i>
PANEL A	LOG LEVELS			
$\ln(y_{it}) - \ln(y_{i,t-1})$	467.211***	-19.024***	-20.352***	-3.980***
$\ln(y_{i,t-1})$	84.462*	0.170	0.276	-2.718**
$\ln(s_{kit})$	105.107***	-0.309	-3.378***	-2.146*
$\ln(n_{it} + \omega + \delta_{it})$	344.387***	-13.340***	-15.266***	-3.627***
$\ln(\phi_{H_{it}})$	90.018***	0.796	-3.546***	-2.539*

⁵² As discussed above, the system GMM estimator improves the precision and ensures the consistency of the necessary restrictions on the initial conditions within the standard Solow growth framework even when the series in the panel are highly persistent (Blundell and Bond, 2000; Bond, 2002; Bond *et al.*, 2001).

⁵³ For the health variable— $1/L_{UH_{it}}$ —used in the analysis, Table 2 does not report the results of PURTs since the test statistics are exactly the same as those obtained for the variable $L_{UH_{it}}$.

⁵⁴ Since the data were originally provided in five-year intervals, no unit root test can be performed for the series of health variables in the second sample (*i.e.*, for life expectancies at ages 15 to 60 and adult mortality).

$\ln(L_{UH_{it}})$	63.849***	1.281	-2.177**	-2.141*
$\ln(1 - \tau_{it})$	98.108***	-1.859**	-2.546***	-2.417*
$\ln(\tau_{it})$	95.154**	-1.703**	-2.407***	-2.786**
$\ln(taxr_{it})$	132.533***	-3.053***	-4.200***	-2.355*
$\ln(gov_{it})$	83.642*	-2.037**	-0.952	-2.820***
$\ln(HC_{it})$	98.211***	-1.455*	0.470	-2.303*
$\ln(OPEN_{it})$	154.837***	-4.881***	-5.683***	-2.742**
PANEL B FIRST DIFFERENCES IN LOGS				
$\ln(y_{it}) - \ln(y_{i,t-1})$	930.104***	-16.479***	-33.917***	-4.634***
$\ln(y_{i,t-1})$	447.503***	-17.638***	-19.721***	-3.864***
$\ln(s_{K_{it}})$	626.437***	-18.596***	-20.492***	-3.676***
$\ln(n_{it} + \omega + \delta_{it})$	590.083***	-17.814***	-23.967***	-3.480***
$\ln(\phi_{H_{it}})$	327.343***	-8.318***	-13.195***	-2.946***
$\ln(L_{UH_{it}})$	351.537***	-10.536***	-14.014***	-3.684***
$\ln(1 - \tau_{it})$	443.253***	-15.774***	-19.038***	-4.569***
$\ln(\tau_{it})$	404.579***	-13.699***	-17.494***	-4.645***
$\ln(taxr_{it})$	419.996***	-16.359***	-18.451***	-4.283***
$\ln(gov_{it})$	419.629***	-16.719***	-18.328***	-3.696***
$\ln(HC_{it})$	254.288***	-5.784***	-7.365***	-3.028***
$\ln(OPEN_{it})$	806.554***	-16.030***	-24.028***	-3.017***

Notes: For each test, the null hypothesis tests the existence of unit root. An intercept and a linear time trend are included in each test for each series. Akaike's Information Criterion (AIC) is used to determine the optimal lag lengths. ***, **, and * refer to significance levels of 1%, 5%, and 10%, respectively.

Table 3: Results of PURTs - Sample Set 2

	<i>FISHER</i> <i>ADF</i>	<i>LLC</i> <i>Adjusted t*</i>	<i>IPS</i> <i>W-t-stat.</i>	<i>PESARAN</i> <i>CIPS</i>
PANEL A LOG LEVELS				
$\ln(y_{it}) - \ln(y_{i,t-1})$	823.657***	-30.339***	-30.006***	-3.774***
$\ln(y_{i,t-1})$	107.910**	-2.558***	-1.418*	-2.613*
$\ln(s_{K_{it}})$	208.669***	-3.848***	-7.946***	-2.252*
$\ln(n_{it} + \omega + \delta_{it})$	511.562***	-21.099***	-19.716***	-3.500***
$\ln(1 - \tau_{it})$	115.732***	-2.142**	-2.988***	--- ⁵⁵
$\ln(\tau_{it})$	124.875***	-126.169***	-3.657***	---
$\ln(HC_{it})$	85.948	-2.710***	-0.212	-2.910***
$\ln(OPEN_{it})$	316.866***	-11.801***	-12.212***	-3.039***
PANEL B FIRST DIFFERENCES IN LOGS				
$\ln(y_{it}) - \ln(y_{i,t-1})$	915.367***	-5.153***	-33.253***	-4.385***
$\ln(y_{i,t-1})$	786.390***	-29.385***	-28.859***	-3.766***
$\ln(s_{K_{it}})$	925.711***	-33.890***	-32.701***	-3.675***
$\ln(n_{it} + \omega + \delta_{it})$	795.455***	-15.766***	-28.851***	-3.531***
$\ln(1 - \tau_{it})$	642.540***	-22.106***	-24.496***	---
$\ln(\tau_{it})$	678.035***	-22.462***	-24.425***	---

⁵⁵ Pesaran's CIPS (2007) test cannot be applied to the annual series on $\ln(1 - \tau_{it})$ and $\ln(\tau_{it})$ as they are highly unbalanced for the second sample.

$\ln(HC_{it})$	99.352**	3.043	-2.196**	-4.238***
$\ln(OPEN_{it})$	988.012***	-33.276***	-35.491***	-4.201***

Notes: For each test, the null hypothesis tests the existence of unit root. An intercept and a linear time trend are included in each test for each series. AIC is used to determine the optimal lag lengths. ***, **, and * refer to significance levels of 1%, 5%, and 10%, respectively.

Tables 4–8 report the results of system GMM estimations. In all regressions, the LHS variable is the change in the logarithm of real output per worker. The lagged log-level of real output per worker is treated as predetermined, and all independent variables are considered endogenous, *i.e.*, they are assumed to be correlated with the shocks to real output per worker both in the current and in the previous periods (*e.g.*, in five-year periods). In growth studies, as in Hoeffler (2002) and Ding and Knight (2011), the augmented rate of population growth is generally assumed to be exogenous. However, in this study, the augmented growth rate of the labor force is treated as potentially endogenous, following Cho (1996) and Bond *et al.* (2001). That is, the rate of labor force growth is also allowed to correlate with current and past shocks to real output given the argument that the change in income affects fertility decisions and mortality rates, and hence the rates of population and labor force growth (Barro and Becker, 1989; Jones, 1997; Kalemli-Ozcan, 2003; Nerlove and Raut, 1997; Prettnner, 2013). Time dummies are also included in all regressions. The inclusion of time dummies helps to prevent possible evidence of simultaneous correlation since the GMM estimators assume that the disturbances are uncorrelated across individuals (Roodman, 2009a).

Each model is estimated by using a one-step GMM estimator. In fact, the majority of the studies employing GMM estimators often rely on the results of one-step estimators, though it is argued that a two-step estimator is always more efficient than its one-step counterpart (Blundell *et al.*, 2001; Bond *et al.*, 2001; Ding and Knight, 2009; Hoeffler, 2002). This is because (i) the efficiency gains from using a two-step estimator are very small for system GMM and a one-step estimator is more reliable for finite sample inference even in cases of non-normality and heteroskedasticity (Blundell and Bond, 1998: 142) and (ii) unlike a two-step estimator, the independence of the weight matrix on a one-step estimator that includes the estimated parameters or residuals allows the approximations on familiar asymptotic distributions to become more precise (Blundell and Bond, 2000; Bond and Windmeijer, 2002). The results of

Monte Carlo experiments have further shown that the asymptotic t -ratios can be seriously misleading for two-step estimators but not for one-step estimators (Bond, 2002: 147). Therefore, based on the discussion above, the inferences in this study are based on the findings obtained from the use of one-step system GMM estimators.

The bottom part of each of Tables 4–8 provides the test statistics to verify the consistency of system GMM results, which can be tested by the following key conditions: First, the consistency of the estimator depends on the validity of the set of instrumental variables, which requires that the instruments and error term be uncorrelated. This condition is tested by means of the Hansen (1982) test of overidentifying restrictions.⁵⁶ Hansen (1982) has suggested the J -statistic to test the null hypothesis that all instruments are valid. Hence, the non-rejection of the null implies that the instruments and error term are uncorrelated, *i.e.*, the instrument set is valid. Second, the system GMM requires that the extra moment restrictions imposed by Blundell and Bond (1998) be valid. The C -statistic produced by the difference-in-Hansen test is used to test the null of the validity of these subsets of instruments, which distinguishes the system estimator from the difference one (Blundell and Bond, 2000). Hence, it tests the exogeneity of instrument subsets. Both J - and C -statistics asymptotically follow a chi-square distribution, with degrees of freedom equal to the degree of overidentification and the number of suspect instruments, respectively. The p -values of the test statistics given at the bottom part of each table show that the instruments and their subsets are valid in all estimations.

Third, the existence of the autocorrelation in the disturbance term should be checked to avoid using some lags as invalid instruments. In fact, there can be negative first-order serial correlation in differences, but the existence of it is not informative (Roodman, 2009a: 119). However, there should be no second- and higher-order autocorrelation. To this end, Arellano and Bond (1991) have developed a z -test applied to the disturbances in differences to detect autocorrelation aside from the fixed effects for the dynamic panel model. In general, the test considers the serial correlation of order $AR(k + 1)$ in the differences to check for the serial correlation in order $AR(k)$ in levels. Hence, the test detects lagged instruments that become invalid through

⁵⁶ The test was first proposed by Sargan (1958) and extended to the more general nonlinear GMM framework by Hansen (1982).

autocorrelation. The idea behind the test lies on the fact that if the disturbances are serially correlated in order k then, $y_{i,t-(k+1)}$ is endogenous to the k^{th} lag of the disturbance term in the error term in differences and becomes a potentially invalid instrument (Roodman, 2009a: 119). In this case, the instrument set should be restricted to lags $k + 2$ and longer of y_{it} . Tables 4–8 provide the p -values for Arellano-Bond test statistics for first- ($AR(1)$) and second-order autocorrelation ($AR(2)$). The results in all columns show that there is no second-order serial correlation. Lastly, the number of groups used in regression should be greater than or equal to the number of instruments to eliminate overfitting endogenous variables (Roodman, 2009a). This requirement is also met in each estimation.

Table 4 below provides the estimation results for the first sample that includes the healthy working time of workers but excludes the effect of the government. Column (1) provides the estimation results for the absolute convergence equation given in Eq. (21d), which is the case when a group of economies tend to converge to the same steady state. All the other columns (2)–(10) deal with the versions of the conditional convergence equations given in Eqs. (21c) and (21b). According to the results in column (1), the coefficient on the lagged log-level of real output per worker is significantly negative, indicating that 33 OECD members converge in an absolute sense, but the implied rate of convergence (λ) is around 3.2% per annum.⁵⁷ The estimated rate of absolute convergence is higher than the rate found in the studies of Dowrick and Nguyen (1989) and Mankiw *et al.* (1992), among others, who have reported an annual rate of around 2% among OECD countries.

Column (2) of the table shows the results based on the estimation of the basic Solow model as shown in Eq. (21c), which neglects the role of health. The significant coefficient of initial output per worker implies the existence of conditional output convergence among OECD members. In line with the findings of the convergence empirics, the results of the study provide support for absolute and faster conditional output convergence among structurally similar high-income countries (Barro, 1991; Barro and Lee, 1993, 1994; Barro and Sala-i-Martin, 1990; Islam, 1995; Mankiw *et al.*, 1992). The estimated effect of the savings rate is significantly positive, as expected. However, the effect of the augmented rate of workforce growth is negative but

⁵⁷ The calculations for implied convergence rates presume $\tau = 5$ for each table.

insignificant. The results also show that the estimated share of capital (α) is 0.619 for 33 OECD countries over the sample period, which is remarkably higher than the Solow model's prediction of one third as given in Mankiw *et al.* (1992).

The results in column (2) also show that the implied convergence rate (λ) is about 4.7% per annum, conditional on the rates of savings and augmented growth of the labor force. This finding indicates that OECD countries move halfway to the steady state in about 15 years.⁵⁸ However, in earlier studies, it has been occasionally claimed that the convergence literature has found “*a mnemonic rule*” of two percent for the speed of convergence even for diverse economic units and time samples (Sala-i-Martin, 1996b: 1326). In this sense, Quah (1996) has argued that the rate of 2% arises from the unit root processes that exist in the time dimension of the data (Quah, 1996: 1355-1361). Furthermore, these estimates have been mostly obtained by using cross-sectional regressions, and the bias estimates of this methodology on the lagged dependent variable significantly bias the estimated rates of convergence. Subsequently, a few studies have shown that correcting for the bias resulting from endogeneity and unobserved heterogeneity in TFP levels produces higher estimates of convergence rates, contrary to conventional wisdom.

In particular, the shift in empirical methodology following the studies of Knight *et al.* (1993), Barro and Lee (1993), Islam (1995), and Barro (1996a) has led to higher estimated rates of convergence. These studies that have used more advanced panel data methods to model unobserved heterogeneity in technological differences have shown that the estimated convergence rates are substantially higher at a level of 4%–6% (Islam, 2003: 325-326). The GMM estimates also provide even higher estimated rates of convergence of about 10% and higher (Caselli *et al.*, 1996; Gyimah-Brempong and Wilson, 2004). The findings of this study also confirm these empirical results. Moreover, in their study, Abreu *et al.* (2005) have examined empirical studies on growth to question “*the myth of the 2% convergence rate*” and shown that the estimates on the speed of convergence directly depend on the sample and methodology used. Therefore, it is difficult to pronounce a constant rather than a random rate of convergence (Abreu *et al.*, 2005).

⁵⁸ The half-life formula is $T = \ln(2)/\lambda^*$, where λ^* is the estimated rate of convergence and T is the number of years needed for half the gap between the initial and steady-state level of real output per worker to be eliminated.

Columns (3)–(6) of Table 4 present the estimation results for the theory-backed convergence equation given in Eqs. (10) and (21b) without including control variables. The share of healthy workers is proxied by the share of healthy time per worker spent at work ($\phi_{H_{it}}$) and also the inverse of absent days from work due to illness per worker ($1/L_{UH_{it}}$). The estimations further include the original data—the number of absent days from work due to illness per worker—and its hourly version to proxy for the number of unhealthy workers ($L_{UH_{it}}$) in an economy. These two indicators are included in the analyses to check for the robustness of the calculations, *i.e.*, whether the original and converted data provide consistent results and work in the same way in the estimations. The results indicate that, in line with the results of the theoretical model, the share of healthy working hours in total working hours has a positive and highly significant effect on the growth rate of real output per worker. The findings show that a 1% increase in the share of healthy working hours leads to about a 0.58% increase in the growth rate of real output per worker. The estimated coefficient on the inverse of absent days is also positive and significant, implying that an increase in healthy working days positively and significantly enhances per-worker output growth.

The results further show that absent days or hours from work due to illness have a negative and significant effect on per-worker output growth. Furthermore, in each column (3)–(6), the coefficient on the lagged log-level of per worker output is highly significant and negative. This finding indicates the existence of conditional output convergence among 33 OECD countries, which gains further speed with the inclusion of health proxies in the regressions. In each column (3)–(6), the results show that the estimated rates of convergence, conditional on healthy working time or absent time due to ill health, are around 6%, implying that OECD countries will move halfway to the steady state in about 11 years by decreasing sickness absenteeism through improvements in workforce health in addition to investments in physical capital. In addition, when compared to the results in column (2), the estimated regressions in columns (3)–(6) give a relatively smaller weight to physical capital as the output share of labor significantly increases with the inclusion of health proxies, which is approximately 0.5 percent in each column. The findings in columns (3)–(6) further show that the coefficient on savings rate is positive and significant in each estimation. However, its coefficient is lower in magnitude in each column than that obtained in

column (2). In other words, controlling the healthy share of the labor force in the regressions leads to lower estimated rates of savings compared to those obtained from the estimation of the basic Solow model, which assumes the whole workforce is always healthy. The results further show that the augmented growth rate of the workforce has a negative and insignificant effect on output growth in all columns between (3)–(6).

Columns (7)–(10) of Table 4 include human capital and trade openness as control variables in the regressions. The results show that in each column, educational human capital and trade openness have an insignificant effect on output growth and the convergence process when the regressions simultaneously include health proxies. The results are in line with the findings of Knowles and Owen (1995, 1997) and Heshmati (2001), who similarly reported that the coefficient on human capital in the form of education is insignificant in all regressions that include health indicators. In this sense, the results of this study significantly show that good health is a stronger determinant of output growth than education (Barro and Lee, 1993, 1994; Knowles and Owen, 1995; Weil, 2007). This finding may also imply that good health is also a primary condition for the formation and development of other types of human capital, including education. Moreover, by contributing to the ongoing debate on the nexus between openness and economic growth, the results of the study show that openness to trade has a negative but insignificant effect on output growth. In this sense, some previous studies on empirical growth have found a positive and significant relationship between trade openness and growth (Barro, 1991; Dollar and Kraay, 2004; Sachs and Warner, 1995; Sala-i-Martin *et al.*, 2004). However, in line with the findings of this study, several studies have argued that standard measures of trade openness are not robustly and significantly correlated with economic growth (Rodríguez, 2007; Ulaşan, 2015), while others have found a negative and significant relationship between openness and economic growth (Belazreg and Mtar, 2020; O’Rourke, 2000).

On the other hand, the results in columns (7)–(10) show that controlling human capital in the form of education and openness to trade does not lead to a significant change in the previous findings found in columns (3)–(6). In other words, the findings indicate that all health proxies showing the impact of healthy working hours (sickness absenteeism) have positive (negative) and significant effects on the growth rate of real output per worker. The coefficient on the lagged log-level of per worker output is

significant and negative, showing the existence of conditional output convergence at an estimated rate of around 6%, which is similar to those found in columns (3)–(6). The findings further show that the savings rate has a positive and significant effect on output growth in columns (7)–(10) but the augmented rate of workforce growth has a negative but insignificant effect.

Table 5 shows the estimation results for the first sample that includes both health and government variables as in Eqs. (20) and (21a). In each column (1)–(5), the regressions include the share of healthy working hours as a proxy for the share of healthy workers, and the variables related to government policy are added alternately to the models. The last column (6) further includes the control variables and gives the estimate of the complete empirical model given in Eq. (21a). In this sense, column (1) gives the results on output convergence, conditional on the rates of savings, the augmented rate of workforce growth, healthy working hours, and the shortfall of the income tax rate ($1 - \tau_{it}$). The results show that the effect of the shortfall, which theoretically refers to the sum of the effects of marginal propensities of savings (MPS), consumption (MPC), and net exports, is positive and insignificant. The findings in column (2) further show that the income tax rate (τ_{it}) proxied by the taxes on income, profits, and capital gains has a negative but insignificant effect on output growth.

Column (3) shows the findings from the regression that includes both the income tax rate and its shortfall simultaneously, as in Eq. (20). However, the findings are similar to those found in columns (1) and (2) in the sense that the coefficients on both income tax and its shortfall are insignificant. This is in parallel to the findings of Koester and Kormendi (1989), Garrison and Lee (1992), and Mendoza *et al.* (1997), who found an insignificant relationship between distortionary marginal income tax rates and economic growth. Furthermore, given the results in each column, the signs of their coefficients are also erratic. On the other hand, the findings show that the share of healthy workers still significantly and positively contributes to output growth and the convergence process, but its significance is low compared to the results in Table 4. The coefficient on the initial log-level of output is significantly negative in each column (1)–(3), indicating evidence of conditional convergence among OECD members. The estimated rates of convergence are around 6% per year, similar to those

obtained in Table 4.⁵⁹ The results in columns (1)–(3) further show that the savings rate has a positive and significant impact on growth, while the augmented rate of workforce growth has a negative but insignificant effect.

Columns (4) and (5) re-estimate the model given in column (2) by proxying the income tax rate with the shares of tax revenue and government expenditures in total GDP, *i.e.*, $\tau_{it} = \frac{G_{it}}{Y_{it}} = \frac{TAXR_{it}}{Y_{it}}$. The findings show that the share of tax revenues has no role in explaining output growth among OECD countries. This finding is in line with the results of previous studies that have found an insignificant relationship between tax revenues and growth (Koester and Kormendi, 1989; Lee and Gordon, 2005; Mendoza *et al.*, 1997; Xing, 2011). On the other hand, the share of government expenditures has a significant and negative impact on output growth. This finding may reflect the fact that, in some cases, expenditures of the government further impose an additional significant burden on country economies, given the most OECD countries had larger budget deficits during the sample period (OECD, 2015).

In practice, government size has two opposite effects on a country's economy.⁶⁰ Higher government consumption (big government) offset through higher tax rates can lead to (i) higher distortions in the economy due to a lack of growth-enhancing public spending or (ii) a higher stimulus for investment and growth if transferred reasonably. The former unfortunately refers to one of the features of government expenditures, which can be characterized as “*bullets fired into the sky*” (Yetkiner, 2010). In this context, the findings of the recent literature on the growth effects of government size—mostly proxied by the shares of government expenditures and tax revenues in GDP—are mixed and inconclusive in a way that makes it difficult to infer any policy implications. Nevertheless, the findings of this study are in line with those of Barro (1991), Fölster and Henrekson (2001), Romero-Ávila and Strauch (2008), and Bergh and Karlsson (2010), who have found that the share of total government expenditures is negatively related to economic growth in high-income countries.

⁵⁹ It should be noted that the estimated output share of physical capital cannot be calculated in Eq. (20).

⁶⁰ Note that in the theoretical model in Section 1.3., both output and government spending are assumed to be endogenous variables, while the income tax rate is a constant parameter.

Table 4: System GMM Estimations: Sickness Absenteeism and Control Variables

Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\ln(y_{it-1})$	-0.147*** (0.051)	-0.211*** (0.043)	-0.270*** (0.044)	-0.275*** (0.052)	-0.266*** (0.047)	-0.267*** (0.047)	-0.279*** (0.065)	-0.263*** (0.061)	-0.263*** (0.059)	-0.263*** (0.059)
$\ln(s_{kit})$		0.343*** (0.068)	0.264*** (0.099)	0.262** (0.104)	0.247** (0.105)	0.247** (0.105)	0.234** (0.106)	0.227** (0.104)	0.222** (0.103)	0.222** (0.104)
$\ln(n_{it} + \omega + \delta_{it})$		-0.030 (0.025)	-0.027 (0.031)	-0.007 (0.032)	-0.011 (0.030)	-0.010 (0.031)	-0.030 (0.031)	-0.015 (0.030)	-0.017 (0.029)	-0.017 (0.029)
$\ln(\phi_{hit})$ (hours)			0.580*** (0.219)				0.603** (0.236)			
$\ln(1/L_{0H_{it}})$ (days)				0.088** (0.041)				0.050* (0.028)		
$\ln(L_{0H_{it}})$ (hours)					-0.079* (0.040)				-0.054** (0.025)	
$\ln(L_{0H_{it}})$ (days)						-0.080* (0.041)				-0.054** (0.025)
$\ln(HC_{it})$							0.270 (0.183)	0.273 (0.180)	0.284 (0.178)	0.280 (0.178)
$\ln(OPEN_{it})$							-0.008 (0.019)	-0.005 (0.017)	-0.005 (0.017)	-0.005 (0.017)
Constant	1.700*** (0.588)	1.366*** (0.497)	2.361*** (0.518)	2.498*** (0.673)	2.693*** (0.731)	2.448*** (0.645)	2.239*** (0.509)	2.087*** (0.497)	2.270*** (0.525)	2.100*** (0.488)
Implied λ (%)	3.18%	4.74%	6.31%	6.43%	6.19%	6.20%	6.53%	6.11%	6.10%	6.09%
Implied α		0.619	0.494	0.488	0.481	0.481	0.457	0.463	0.458	0.458
AR(1)	0.227	0.435	0.527	0.593	0.546	0.543	0.585	0.570	0.550	0.551
AR(2)	0.139	0.288	0.202	0.179	0.207	0.207	0.184	0.224	0.232	0.233
J-stat	0.272	0.221	0.203	0.189	0.174	0.179	0.156	0.164	0.148	0.159
C-stat	0.706	0.656	0.897	0.981	0.953	0.953	0.912	0.863	0.830	0.852
# of instruments	28	31	31	31	31	31	31	31	31	31
# of groups	33	33	33	33	33	33	33	33	33	33

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ and α show the estimated convergence rate and the estimated output share of physical capital, respectively. J-stat and C-stat show the p-values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p-values for the z-test statistics that show serial correlation of order $AR(k+1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Table 5: System GMM Estimations: Sickness Absenteeism, the Government, and Control Variables

Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(y_{it-1})$	-0.244*** (0.058)	-0.268*** (0.054)	-0.253*** (0.057)	-0.266*** (0.063)	-0.332*** (0.048)	-0.308*** (0.079)
$n(s_{kit})$	0.264** (0.099)	0.256*** (0.093)	0.280** (0.106)	0.208* (0.115)	0.251*** (0.087)	0.326*** (0.107)
$\ln(n_{it} + \omega + \delta_{it})$	-0.021 (0.033)	-0.013 (0.032)	-0.013 (0.033)	-0.004 (0.030)	-0.024 (0.032)	-0.026 (0.032)
$\ln(\phi_{H_{it}})$ (hours)	0.379* (0.193)	0.486** (0.212)	0.368* (0.186)	0.737* (0.393)	0.302* (0.163)	0.266 (0.223)
$\ln(1 - \tau_{it})$	0.035 (0.077)		0.099 (0.138)			-0.107 (0.107)
$\ln(\tau_{it})$		-0.013 (0.079)	0.070 (0.141)			-0.105 (0.092)
$\ln(taxr_{it})$				0.235 (0.150)		
$\ln(gov_{it})$					-0.191** (0.077)	
$\ln(HC_{it})$						0.306 (0.237)
$\ln(OPEN_{it})$						-0.006 (0.006)
Constant	1.886* (0.934)	2.361*** (0.550)	1.410 (0.940)	1.765** (0.660)	3.620*** (0.808)	2.989** (1.189)
Implied λ (%)	5.61%	6.23%	5.85%	6.19%	8.07%	7.37%
AR(1)	0.559	0.500	0.656	0.496	0.502	0.524
AR(2)	0.241	0.205	0.231	0.184	0.257	0.280
J-stat	0.281	0.325	0.164	0.286	0.167	0.133
C-stat	0.799	0.844	0.952	0.960	0.910	0.349
# of instruments	32	32	31	32	32	31
# of groups	33	33	33	33	33	33

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rates. J-stat and C-stat show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values for the z-test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * show the significance levels of 1%, 5%, and 10%, respectively.

Finally, the last column (6) of Table 5 gives exactly the estimation results of the model in Eq. (21a) by adding the control variables into the regression. However, the results show that all coefficients are insignificant, except for the initial log-level of output and the savings rate. In this sense, the findings in columns (4)–(6) further indicate that the coefficient on the healthy share of the workforce remains positive and significant in each column, except for column (6). However, its significance is small compared to the findings found in Table 4. The results in columns (4)–(6) further show that the savings rate has a positive and significant impact on output growth. However, its coefficient has the lowest magnitude if the regressions are controlled by the share of tax revenues in column (4). Furthermore, the lagged log-level of per-worker output is negative and significant in each column, indicating evidence of conditional convergence among OECD countries. The estimated rates of convergence are still around 6% per annum, except for column (5). In column (5), in which the effects of government expenditures are considered, the highest rate of convergence of about 8% is estimated. This finding suggests that decreasing the growth-diminishing effects of government spending may help OECD countries close their output gaps more quickly.

Moreover, the findings show that in each column (4)–(6), the augmented rate of workforce growth has a negative but insignificant impact on output growth among OECD countries. All in all, the findings from Tables 4 and 5 significantly show that the share of healthy workers in the total workforce has a positive and sizeable effect on output convergence and long-run growth in OECD countries, as its coefficients remain significantly positive in all regressions. In other words, the findings significantly imply that sickness absenteeism due to poor health incurs higher costs to OECD countries in terms of reduced productivity, lower savings, and hence lower long-run output growth. The findings of this study strongly reinforce the overall results of the previous empirical studies, although it is misleading to make a direct comparison between them and this study due to several differences in the proxy being used, the methodological approach, and the sample employed. Nevertheless, the findings substantially reinforce the overall conclusions of Rivera and Currais (1999a, 1999b), Heshmati (2001), and Gyimah-Brempong and Wilson (2004), who have found a positive and significant effect of various health proxies on growth across OECD countries. However, the results of this study

contradict the results of Knowles and Owen (1995, 1997) and McDonalds and Robert (2002), who reported an insignificant effect of health on high-income OECD countries.

Tables 6–8 provide the estimation results for the second sample, which includes age-specific measures of life expectancy and adult mortality to proxy for the health status of the working-age population. In this sense, Table 6 shows the findings from the estimation of Eq. (21b) without including control variables, Table 7 adds control variables to the model, and Table 8 presents the results of the empirical model with the government variables given in Eq. (21a). Column (1) in Table 6 provides the estimation results for absolute output convergence in Eq. (21d). According to the results, the coefficient on the lagged log-level of output per worker is significantly negative, indicating that 38 OECD members converge in an absolute sense at an implied rate of around 5% per annum. Column (2) shows the estimation results for the conditional income convergence equation given in Eq.(21c), which indicates the existence of conditional output convergence among OECD members. The estimated rate is around 7% per year, which is higher than the rate of the absolute one, in line with the findings of the empirical literature on growth. The savings rate has a significantly positive effect on output growth, while the augmented rate of workforce growth is negative but statistically significant in this case over the sample period between 1955 and 2019. Furthermore, the estimated share of physical capital (α) is 0.472, which is still higher than the predictions of the Solow model.

Columns (3)–(8) of Table 6 show the findings when life expectancy is included in the regressions as a proxy for the health status of the labor force. In each column, the results show that longer life expectancy positively and significantly enhances output growth, except for the life expectancy at ages 50 and 60. Moreover, the magnitude and significance of the coefficients on longevity gradually decrease with age, especially for those age groups that are approaching the end of their working lives. In this sense, the largest estimated growth effect of longevity is obtained at ages 15 and 20, indicating that a 1% increase in life expectancy at ages 15 and 20 is associated with about a 1.7% increase in the growth rate of real output per worker. That is, increases in the life expectancy of those just entering the labor market provide the largest contribution to output growth. This finding confirms the results of Ehrlich and Lui (1991), who have shown that increases in young-age longevity probably result in a larger increase in economic growth.

Table 6: System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups

Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\ln(y_{it-1})$	-0.226*** (0.073)	-0.286*** (0.070)	-0.379*** (0.071)	-0.386*** (0.071)	-0.349*** (0.066)	-0.337*** (0.063)	-0.321*** (0.059)	-0.299*** (0.051)	-0.360*** (0.083)
$\ln(s_{kit})$		0.256*** (0.080)	0.269** (0.103)	0.261** (0.099)	0.296*** (0.104)	0.308*** (0.104)	0.314*** (0.102)	0.336*** (0.102)	0.228** (0.088)
$\ln(n_{it} + \omega + \delta_{it})$		-0.184*** (0.066)	-0.274*** (0.096)	-0.271*** (0.096)	-0.282*** (0.100)	-0.283*** (0.100)	-0.277*** (0.101)	-0.281*** (0.104)	-0.196** (0.080)
$\ln(L15_{it})$			1.662** (0.770)						
$\ln(L20_{it})$				1.671** (0.754)					
$\ln(L30_{it})$					1.167* (0.652)				
$\ln(L40_{it})$						0.931* (0.540)			
$\ln(L50_{it})$							0.705 (0.460)		
$\ln(L60_{it})$								0.522 (0.413)	
$\ln(MRT_{it})$									-0.172** (0.084)
<i>Constant</i>	2.597*** (0.824)	2.818*** (0.936)	-2.968 (2.826)	-2.781 (2.633)	-1.014 (2.222)	-0.058 (1.769)	0.743 (1.410)	1.232 (1.130)	4.494*** (1.397)
<i>Implied λ (%)</i>	5.12%	6.75%	9.53%	9.75%	8.58%	8.23%	7.73%	7.10%	8.91%
<i>Implied α</i>		0.472	0.415	0.403	0.459	0.477	0.495	0.530	0.388
<i>AR(1)</i>	0.022	0.002	0.001	0.001	0.001	0.002	0.002	0.002	0.006
<i>AR(2)</i>	0.114	0.118	0.151	0.186	0.134	0.113	0.113	0.116	0.159
<i>J-stat</i>	0.209	0.297	0.156	0.182	0.141	0.106	0.143	0.112	0.115
<i>C-stat</i>	0.773	0.497	0.597	0.477	0.635	0.541	0.611	0.582	0.254
<i># of instruments</i>	17	36	32	32	32	32	32	32	36
<i># of groups</i>	38	38	38	38	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ and α show the estimated convergence rate and the estimated output share of physical capital, respectively. J -stat and C -stat show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. $AR(1)$ and $AR(2)$ are the p -values for the z -test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * refer to levels of significance of 1%, 5%, and 10%, respectively.

Table 7: System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups and Control Variables

Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln(y_{it-1})$	-0.345*** (0.057)	-0.350*** (0.058)	-0.338*** (0.057)	-0.361*** (0.068)	-0.299*** (0.061)	-0.279*** (0.058)	-0.331*** (0.066)
$\ln(s_{kit})$	0.378*** (0.121)	0.366*** (0.116)	0.386*** (0.120)	0.356*** (0.118)	0.323*** (0.106)	0.340*** (0.112)	0.362*** (0.119)
$\ln(n_{it} + \omega + \delta_{it})$	-0.213* (0.117)	-0.206* (0.109)	-0.224* (0.117)	-0.264** (0.126)	-0.297** (0.116)	-0.324*** (0.122)	-0.241* (0.122)
$\ln(L15_{it})$	1.488* (0.750)						
$\ln(L20_{it})$		1.404* (0.731)					
$\ln(L30_{it})$			1.085* (0.604)				
$\ln(L40_{it})$				0.720 (0.604)			
$\ln(L50_{it})$					0.311 (0.497)		
$\ln(L60_{it})$						0.256 (0.465)	
$\ln(MRT_{it})$							-0.190* (0.097)
$\ln(HC_{it})$	0.084 (0.189)	0.103 (0.187)	0.122 (0.173)	0.220 (0.186)	0.125 (0.153)	0.104 (0.151)	0.115 (0.179)
$\ln(OPEN_{it})$	-0.004 (0.006)	-0.003 (0.005)	-0.003 (0.005)	-0.004 (0.006)	-0.007 (0.008)	-0.005 (0.008)	-0.001 (0.005)
Constant	-3.195 (2.653)	-2.683 (2.485)	-1.374 (1.897)	0.551 (1.970)	1.743 (1.371)	1.817 (1.131)	3.768*** (1.164)
Implied λ (%)	8.47%	8.62%	8.24%	8.96%	7.09%	6.55%	8.05%
Implied α	0.523	0.511	0.533	0.496	0.520	0.549	0.522
AR(1)	0.008	0.006	0.007	0.007	0.002	0.002	0.011
AR(2)	0.127	0.156	0.120	0.138	0.139	0.135	0.112
J-stat	0.118	0.133	0.104	0.121	0.118	0.143	0.113
C-stat	0.790	0.850	0.796	0.830	0.803	0.683	0.629
# of instruments	31	31	31	31	37	37	31
# of groups	38	38	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ and α show the estimated convergence rate and the estimated output share of physical capital, respectively. J-stat and C-stat show the p-values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p-values for the z-test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * are the significance levels at 1%, 5%, and 10%, respectively.

Table 8: System GMM Estimations: Life Expectancy and Adult Mortality by Working-Age Groups, the Government, and Control Variables

Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln(y_{it-1})$	-0.407*** (0.088)	-0.427*** (0.096)	-0.389*** (0.096)	-0.370*** (0.091)	-0.361*** (0.094)	-0.330*** (0.082)	-0.498*** (0.093)
$\ln(s_{kit})$	0.349*** (0.137)	0.347*** (0.141)	0.349*** (0.141)	0.334*** (0.139)	0.330*** (0.145)	0.329*** (0.149)	0.347*** (0.172)
$\ln(n_{it} + \omega + \delta_{it})$	-0.117 (0.111)	-0.112 (0.106)	-0.105 (0.108)	-0.106 (0.112)	-0.077 (0.115)	-0.019 (0.124)	-0.069 (0.099)
$\ln(L15_{it})$	0.056 (0.900)						
$\ln(L20_{it})$		0.196 (0.992)					
$\ln(L30_{it})$			-0.237 (0.803)				
$\ln(L40_{it})$				-0.370 (0.670)			
$\ln(L50_{it})$					-0.523 (0.623)		
$\ln(L60_{it})$						-0.714 (0.534)	
$\ln(MRT_{it})$							-0.107 (0.106)
$\ln(1 - \tau_{it})$	0.014 (0.099)	0.011 (0.105)	0.030 (0.099)	0.034 (0.097)	0.046 (0.101)	0.052 (0.094)	-0.017 (0.122)
$\ln(\tau_{it})$	0.130 (0.109)	0.119 (0.111)	0.151 (0.116)	0.155 (0.113)	0.174 (0.124)	0.178 (0.124)	0.081 (0.132)
$\ln(HC_{it})$	0.343 (0.206)	0.355* (0.207)	0.339 (0.208)	0.335 (0.203)	0.349 (0.214)	0.369 (0.245)	0.398 (0.270)
$\ln(OPEN_{it})$	-0.018 (0.033)	-0.022 (0.035)	-0.027 (0.034)	-0.025 (0.033)	-0.038 (0.033)	-0.051** (0.024)	-0.041 (0.026)
Constant	2.592 (3.244)	2.281 (3.311)	3.407 (2.514)	3.661* (2.012)	3.846** (1.639)	3.783*** (1.294)	4.491** (2.021)
Implied λ (%)	10.47%	11.13%	9.85%	9.23%	8.96%	8.01%	13.76%
AR(1)	0.013	0.016	0.010	0.007	0.018	0.066	0.276
AR(2)	0.274	0.314	0.264	0.248	0.265	0.290	0.478
J-stat	0.114	0.123	0.117	0.136	0.141	0.151	0.106
C-stat	0.373	0.466	0.386	0.493	0.546	0.549	0.478
# of instruments	34	34	34	34	34	34	34
# of groups	38	38	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rates. J-stat and C-stat show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values for the z-test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * show the significance levels at 1%, 5%, and 10%, respectively.

In each column (3)–(8) of Table 6, the significant coefficient on the lagged log-level of the output variable is negative, showing that there is strong evidence of convergence among OECD members. In addition, the inclusion of longevity measures significantly accelerates the convergence process compared to that obtained from the estimation of the basic Solow model in column (2). In this context, the highest rates are found in columns (3)–(4), in which the life expectancy at ages 15 and 20 is included in the regressions. Hence, the findings show that the improvements in the longevity of this age span between 15 and 20 allow OECD countries to converge faster at a rate of about 10% per year. However, this rate gradually decreases to around 9%, 8%, and 7% if the life expectancy at ages 30, 40, 50, and 60 is considered, respectively. The results in columns (3)–(8) further indicate that the coefficients of the standard Solow-convergence variables are highly significant. In this sense, the effect of the savings rate is positive in each column, but its significance and magnitude increase with age after age 20. In this sense, the largest estimated coefficient of savings is obtained in column (8), in which the effect of life expectancy at age 60 is considered. This finding may reflect the fact that longer life expectancy leads individuals to have greater incentives to save for older ages (Lee *et al.*, 2001; Mason and Lee, 2006; Radelet *et al.*, 1997). This finding may further indicate that annual gains in life expectancy for the age groups 50 and 60, which are those approaching the end of their working lives and retirement, indirectly contribute to growth through increases in the savings rate rather than directly through increases in labor productivity.

Furthermore, different from previous results in Tables 4 and 5, the augmented growth rate of the workforce has a significantly negative effect on growth in each column (3)–(8). One reason for this difference may be that the changes in the health status of the labor force through changes in longevity and mortality have significant direct impacts on the age structure and dependency ratios of a country through changes in fertility rates, which in turn influence the rates of population and workforce growth (Bloom and Canning, 2000; Cervallati and Sunde, 2015; Desbordes, 2011; Soares, 2005). However, the number of absent days due to sickness or the share of healthy working days directly affects the production process through changes in productivity rather than directly affecting the demographic characteristics of a country. One more remarkable finding from columns (3)–(5) is that the inclusion of longevity measures

leads to higher estimated output shares for labor. In this sense, the estimated capital shares significantly imply that (i) the improvements in the health status of the population at ages 15-30 result in an increase in the output share of labor, and hence (ii) as assumed by the Solow model, diminishing returns set in quickly, which in turn explains the faster convergence rates of OECD countries obtained in columns (3)–(5). However, the output shares of physical capital are significantly higher in columns (6)–(8), in which the longevity at ages 40, 50, and 60 is considered, and these shares are even higher than those estimated in column (2).

Lastly, column (9) adds adult mortality rates between ages 15 and 60 to the regression, which are a reasonable reverse proxy for good health status (Caselli, 2005: 30). The estimated coefficient of the lagged log-level of output is negative and highly significant, indicating that a 1% decrease in adult mortality leads to about a 0.2% increase in per-worker output growth. The estimated rate of convergence is around 9% per annum, implying that the half-life of convergence among 38 OECD countries could be reduced to about 8 years by decreasing adult mortality between ages 15 and 60. In parallel, the inclusion of adult mortality also remarkably lowers the output share of physical capital to about 0.388 compared to other columns. Moreover, compared to longevity indicators in columns (3)–(8), controlling for adult mortality considerably decreases (i) the positive and significant growth effects of the savings rate and (ii) the negative effect of the workforce growth rate. Hence, the findings from Table 6 significantly show that good health status in terms of increases in longevity and decreases in mortality is a strong predictor of long-run productivity and output growth, as in Cervallati and Sunde (2011), who have stated that sufficiently high longevity is the ultimate stimulator for the transition to sustained growth.

Table 7 gives the results from the estimation of Eq. (21b), which includes age-specific measures of life expectancy, adult mortality, and control variables simultaneously. As before, the results show that the effects of human capital in the form of education and openness to trade have an insignificant effect on output growth. However, in this case, controlling human capital and openness slightly changes the previous findings found in Table 6. In other words, the findings in columns (1)–(7) indicate that (i) although the coefficients of life expectancy at ages 15, 20, and 30 still remain significant, the coefficients of those at ages 40, 50, and 60 become

insignificant, (ii) all coefficients on longevity measures decrease in magnitude compared to Table 6, (iii) the highest estimated rate of convergence of about 9% per annum is now obtained for life expectancy at age 40, and (iv) the negative growth effects of adult mortality slightly increase in magnitude. Hence, one may argue that these changes in the effects of health measures may originate from the fact that life expectancy represents not only the health status of the workforce but more broadly the quality of human capital (Barro, 1996a).

Hence, the inclusion of human capital simultaneously with life expectancy may make it impossible to properly estimate the separate effects of the two variables (Arora, 2001).⁶¹ Note that controlling for human capital does not lead to a significant change in the findings of Table 4, in which health is measured by the share of healthy working hours and the number of absent days due to ill health, as these measures reflect more the morbidity level of the workforce. On the other hand, some general patterns of the findings in Table 6 are also found in Table 7. In this sense, the results show that (i) the coefficients on longevity gradually decrease in magnitude with increasing age, (ii) the largest positive effect of life expectancy is estimated at age 15, (iii) there is strong evidence of conditional output convergence in each column, (iv) the inclusion of longevity measures significantly accelerates the convergence process, (v) the largest output share of physical capital is still obtained in column (6), where the longevity at age 60 is considered, and (vi) in each column, the savings rate has a positive and significant effect on output growth while the workforce growth rate has a significant and negative effect on output growth.

Finally, Table 8 provides the estimation results for the complete empirical model given in Eq. (21a) that includes healthy proxies, government policy, and control variables simultaneously. The results are similar to those obtained in column (6) of Table 5. In this sense, the findings in columns (1)–(7) show that the coefficients of life expectancy and adult mortality become insignificant. Furthermore, although insignificant, the effect of life expectancy becomes increasingly negative in magnitude after age 20. The findings further indicate that the effects of the income tax rate, human

⁶¹ To avoid any possible multicollinearity issue, the study checks for variance inflation factors (VIFs) as a rule of thumb. The results show that the regression models do not suffer from a serious multicollinearity problem, as the mean VIF value is smaller than or equal to 2.32 in all regressions from the first sample set and 2.83 for the second sample set.

capital, and openness to trade are all insignificant, as found before. Human capital has a positive and significant effect on output growth only in column (2), in which the effect of life expectancy at age 20 is considered.

On the other hand, the findings in Table 8 show that there is still strong evidence of conditional output convergence among 38 OECD member countries. The estimated rates of convergence are higher in each column compared to the rates in Tables 6 and 7. The highest rate of around 14% is obtained in column (7), which considers the effect of adult mortality. The results also indicate that the savings rate has a positive and significant impact as one of the key determinants of output growth, but that the workforce growth rate has a negative but insignificant impact on growth. Hence, given the findings in Tables 5 and 8, one may argue that there is a need for more refined control measures on the size of government and also on taxation to obtain more precise results between health indicators and growth, *e.g.*, measures that reflect the effects of income taxation on private health expenditures of households and also the size of the government in health care, which is the topic of Chapter 2 of this thesis.

1.5. CONCLUDING REMARKS AND POLICY IMPLICATIONS

This chapter contributes to understanding the role of workforce health on output growth and convergence. Particularly, the main aim of this chapter is to obtain a testable output convergence equation in a narrowed Solow model, which is narrowed in such a way that it employs only healthy workers in the production. Hence, the novelty in the study is in using the distinction between healthy and unhealthy workers to express the aggregate production function of a standard Solovian economy. The study further extends the above model by assuming the existence of a balanced budget government, whose consumption expenditures are assumed to be endogenous and have a positive externality effect on the production process of the firms. The theoretical findings of the study show that the steady-state values of per-worker variables, including real output, physical capital, consumption, and government expenditures, are all lower than the steady-state values obtained from the solution of the standard Solow model, which assumes that all workers are always healthy.

In other words, increased absence from work due to illness reduces per-worker capital formation, output per worker, and consumption per worker in the long run. The theoretical findings further imply that in the transitional period, the growth rate of a country's per-worker output depends on the initial level of per-worker output, the savings rate, the augmented rate of workforce growth, the share of healthy workers actively engaged in the production process, and the rate of income taxes if the model includes the government. However, although the growth rates of these per-worker variables are different in the transitional period, they all start to grow at the same constant rate of technological progress at long-run equilibrium. That is, as the main prediction of the basic Solow model, technological progress is the main engine of long-run economic growth.

Furthermore, the theoretical results show that increases in the share of healthy workers raise per-worker values of all model variables, including per-worker consumption expenditures of the government. The results also show that income taxes, which are assumed to cover the consumption expenditures of the government by taking a constant share of output, result in a decrease in disposable income for consumers in the absence of externalities. However, if the externality generated by government expenditures is considered, then the results show that the effect of the income tax rate depends on the relative magnitudes of government externality and tax rate. All in all, the theoretical study clearly reveals that the canonical Solow model provides a suitable framework to model and differentiate the role of healthy workers in the growth and convergence processes.

The empirical part of the study provides system GMM estimates of the derived convergence equation. To this end, two separate sample sets were used in the study. In addition to standard Solow-growth variables, the first sample set includes the share of healthy working hours as a proxy for the share of a healthy workforce to highlight the growth implications of absenteeism due to poor health for 33 OECD countries over the 1981-2019 period. On the other hand, the second set includes age-specific measures of life expectancy and adult mortality between ages 15 and 60 to proxy for the health status of the working-age population among 38 OECD countries for the 1955-2019 period. The estimations further include fiscal policy variables in line with the extended theoretical model and also control variables, including human capital in

the form of education and openness to trade. The system GMM estimator is employed in each estimation due to its superior features for empirical growth research.

The main empirical findings of the study show that, in line with the empirics of growth, the findings of the study provide support for absolute and faster conditional output convergence among OECD countries. Second, the findings significantly imply that lower sickness absenteeism enhances productivity, raises capital accumulation, and hence boosts long-run output growth. Third, the results show that the good health status of the workforce, in terms of increases in young- and middle-age longevity and decreases in adult mortality, has a positive, significant, and sizeable impact on the long-run growth performance of OECD countries. Fourth, the findings show that the inclusion of all health proxies significantly increases the speed of output convergence in all estimations. That is, increases in the share of healthy working hours and improvements in the health status of the working-age population—through increases in life expectancy and decreases in adult mortality—help to remarkably reduce the real output differences across OECD members. Last but not least, the use of the system GMM estimator that allows one to correct for finite sample bias, endogeneity, and weak instrument problems produces higher estimated rates of convergence.

Other remarkable details of the empirical findings are as follows: First, the findings of the study show that if the regressions include the share of (un)healthy workers, the estimated rate of convergence is found to be about 6% per year, and this rate remains robust to the inclusion of fiscal policy and control variables. Second, annual gains in young-age longevity significantly increase the speed of convergence, but the estimated convergence rates gradually decrease with rising age after age 20. In this sense, increases in life expectancy at ages 15 and 20 produce the highest increases in the rates of output growth and convergence. Moreover, the positive contribution of life expectancy to growth gradually decreases in magnitude with increasing age, particularly for those that are approaching the end of their working lives. In this sense, the findings show that increases in life expectancy at ages 50 and 60 have an insignificant effect on output growth, while life expectancies at ages 30 and 40 have a significantly positive but modest contribution to growth. Third, by confirming the findings on faster convergence rates, the results further show that the inclusion of all health indicators, including the share of healthy workers, young-age longevity, and

adult mortality, leads to a significant increase in the estimated output shares of labor. However, controlling the longevity of ages 40, 50, and 60 produces relatively higher weights for physical capital.

Fourth, the savings rate has a significant and positive effect on output growth in each regression. However, the positive effects of savings decrease in magnitude when the analyses are controlled for the share of healthy workers, which is always smaller than the total number of workers in practice. Similarly, the rise in adult mortality indirectly lowers the growth-promoting effects of savings across OECD countries. That is, higher adult mortality rates at a country's most active age span significantly lower long-run growth through the loss of human capital at productive ages and by adversely affecting the incentives to invest in physical capital. On the other hand, the findings indicate that the growth-enhancing effects of savings rise remarkably with the increase in the longevity of older people. In this sense, increases in longevity at ages 50 and 60 contribute to output growth indirectly through increases in their savings. Fifth, the workforce growth rate has an insignificant effect on the growth regressions that include the share of healthy workers. However, regarding health status indicators, the rate of workforce growth has a significant and negative effect on output growth, which may indicate evidence that higher longevity and lower mortality decrease the rates of fertility and workforce growth in post-transitional countries, such as most of the OECD members (Hansen and Lønstrup, 2015; Soares, 2005).

Lastly, the results of the study show that human capital and openness to trade have no significant role in explaining output growth among OECD countries. In this sense, the results of the study contribute to the controversial literature and suggest that good health is a more robust determinant of output growth by arguing that it is also a primary condition for the formation and development of other types of human capital, including education. On the other hand, in line with the findings of previous studies, the findings of this study show that standard measures of trade openness are not robustly related to output growth (Rodríguez, 2007; Ulaşan, 2015). Furthermore, the income tax rate and the share of tax revenues in GDP have insignificant effects on the growth of OECD countries. However, the size of government expenditures has a negative impact on the output growth of OECD countries. In this context, this finding

may further indicate the significant burden of government spending among OECD economies, given their larger budget deficits and probably the lack of growth-enhancing public spending.

As a final word, the findings of the study show that the share of healthy workers in the total workforce has a positive and robust effect on long-run growth, as its coefficients remain significantly positive in all regressions, including fiscal policy and control variables. However, importantly, controlling for the policy and control variables in the growth regressions that include longevity and mortality measures significantly changes the effects of these health status indicators. In other words, the findings indicate that the coefficients of life expectancy and adult mortality become insignificant and even negative for ages above 20. In this sense, one may argue that these changes may originate from the diverse nature of health proxies, *i.e.*, healthy working days refer more to the current morbidity levels, while others relate to the current and even future health status. Therefore, it is obvious that there is a need for future research in high-income countries to further understand the growth effects of health status indicators and to clarify the relationship among health, human capital, and fiscal policy variables, as the empirical evidence on their growth effects is weak.

Overall, the findings of the study significantly reveal that workforce health is one of the primary determinants of long-run productivity and output growth. In other words, the results show that a country's ability to remain productive vitally depends on the healthiness of its workforce. In this sense, the policy implications of the study are simple and clear. Policies to boost long-run output growth should promote investments in health, as these investments can be translated into increases in the amount of healthy time available for work through lower rates of absenteeism and increases in the size of the active labor force relative to the population. Similarly, health investments to improve the health status of the existing workforce—through lower adult mortality and higher longevity—will remarkably enhance long-run output growth through the benefits from increases in labor productivity and savings. These improvements will also contribute to a decrease in real output differences among OECD countries. Policy-makers should also notice that increasing health investments, providing health care provisions, and promoting healthier lifestyles for the younger workforce will remarkably contribute to long-run output growth and the faster

elimination of productivity gaps among OECD countries. Furthermore, one of the main objectives of policy-makers to promote economic growth should be to provide an efficient investment environment by means of incentives for the private savings of the elderly workforce.

The findings of the study have further implications for the effects of the COVID-19 pandemic. During the period of the pandemic, there were unprecedented increases in the number of adult deaths, a decrease in life expectancy, and serious working-hour losses due to ill health and prolonged symptoms of COVID-19 in OECD countries. Hence, given the findings of this study, one may expect that the pandemic will seriously cause a decrease in the long-run growth performance of OECD economies through decreases in the size of the active workforce and in labor productivity due to ill health. The negative effects of COVID-19 through increases in mortality and decreases in life expectancy may have further adverse impacts on the incentives for saving, which will further decrease the growth rates of these countries. In this sense, policy-makers need to urgently develop new health-enhancing policy responses to boost the health status of the existing workforce to counteract a possible future productivity slowdown in OECD members.

CHAPTER TWO

INVESTING IN HEALTH: MORE THEORY MORE EVIDENCE

“We also ignore altogether distributional considerations, assuming, in fact, that the way in which consumption and labour are distributed between the members of the community depends solely on their total amounts, so that total satisfaction is a function of these total amounts only. Besides this, we neglect the differences between different kinds of goods and different kinds of labour, ..., so that we can speak simply of quantities of capital, consumption, and labour without discussing their particular forms.”

Ramsey (1928: 543)

2.1. INTRODUCTION

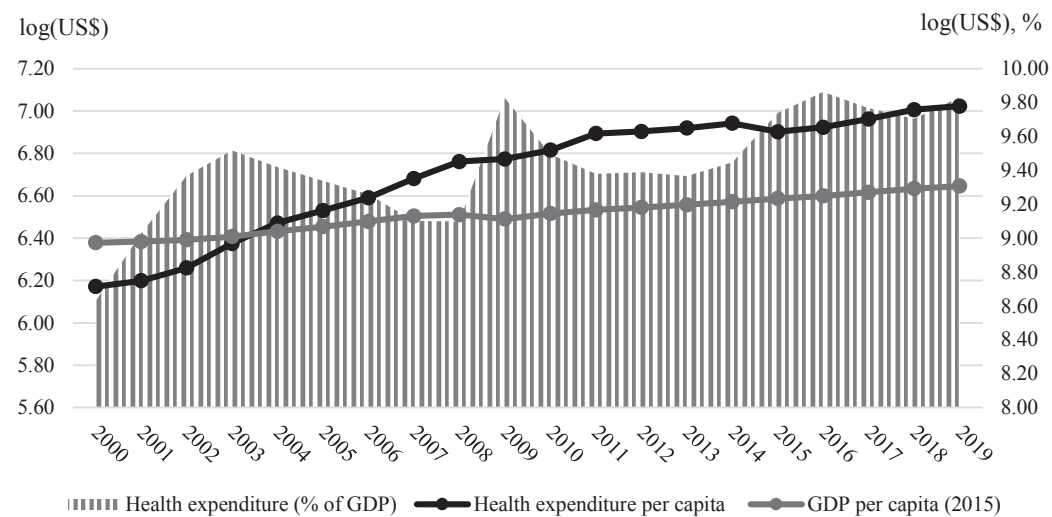
Health care expenditures constitute a large part of health care investments used for the accumulation of health capital. These expenditures are inevitable expenses to maintain and improve the good health status of a society. Therefore, they constitute an important component of a country's total spending cycle. On the other hand, as the other side of the same coin, they impose significant and growing costs on national economies. In this sense, for instance, health expenditures can be likened to government expenditures in nature. In each country, there is an imperative need for government expenditures for the provision of public goods and social services and for the redistribution of limited resources. Therefore, public expenditures are unavoidable and benefit all segments of an economy, including individuals, firms, and communities. However, on the other side, government expenditures generate a serious burden on the economic actors of a society—households and firms—as they mostly come with the cost of taxation. In addition to this, as the decision-makers for these expenditures, governments struggle to reduce their budget deficits while providing public goods and services to society at the cost of taxation. In this context, health-care spending plays a dual role for national economies, as will be discussed further below.

On the one hand, health expenditures are necessary for improving the population's health outcomes in a country.⁶² These expenditures directly raise the

⁶² In this sense, several studies have shown that increases in health expenditures significantly improve the health status of the society—through increases in life expectancy and decreases in mortality—in developed countries (Bradley *et al.*, 2011; Elola *et al.*, 1995; Hitiris and Posnett, 1992; Nixon and Ulmann, 2006; Or, 2000; Wolfe and Gabay, 1987) and in developing or least-developed countries (Adu-

quality and quantity of human capital and further enhance the productivity of the labor force and hence income growth. On the other hand, they constitute a large part of the spending cycle of an economy, particularly a large part of both household and government consumption. Precisely for this reason, these expenditures generate a serious burden on the budgets of their financing sources, which differ depending on the type of health care system adopted in a country. In the meanwhile, the officials of health care systems struggle to meet the rising needs of health care among a country's population while trying to minimize the health care costs endured by this country's economy.

Figure 2: Global Income and Spending on Health



Source: WB, WDI (2022).

By considering the complex nature of health care expenditures, one can look at Figure 2, which shows the global evolutions of log per capita GDP (in US dollars), log per capita health spending (in US dollars), and the percentage share of health expenditures in total GDP. As can be observed from the graph, a rising share of total economic resources has been globally devoted to health care expenditures over the last two decades. In this sense, the share of current health spending shown in the right vertical axis increased from 8.63% in 2000 to 9.83% in 2019, accompanied by an

Acheampong and Jensen, 2019; Anyanwu and Erhijakpor, 2009; Jaba *et al.*, 2014; Sede and Ohemeng, 2015; Ssewanyana and Younger, 2004).

increasing trend in per capita income shown in the same axis. Furthermore, total per capita health care expenditures shown in the left vertical axis (in logs) globally rose from 478.81 US\$ in 2000 to 1121.97 US\$ in 2019, with an increase of about 134.33% (WB, 2022).

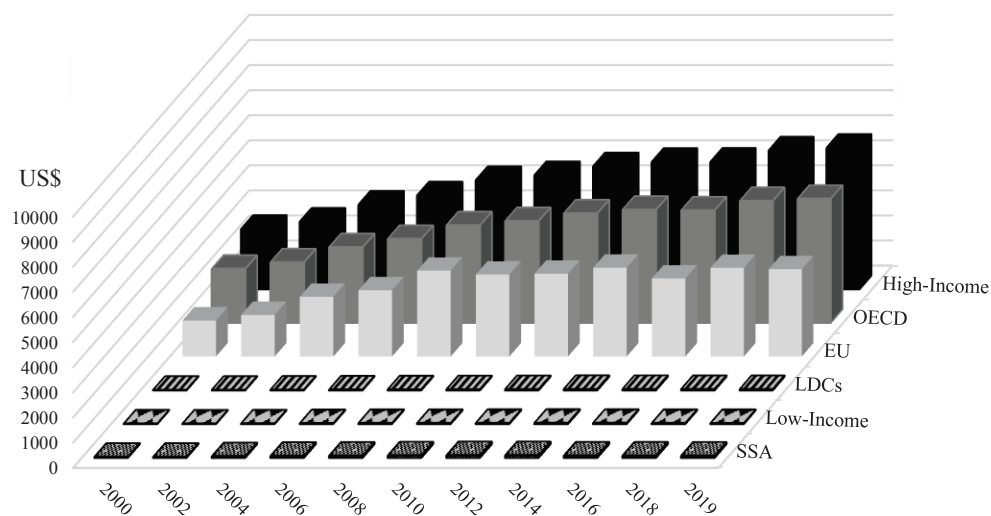
Figure 2 reflects both increasing efforts to obtain better health outcomes and the rising costs of health care expenditures in world economies. Moreover, the figure also illustrates a well-known empirical relationship that exists between per capita health spending and per capita income. In this context, earlier studies have shown that changes in per capita health expenditures are primarily driven by variations in per capita income (Culyer, 1989; Moore *et al.*, 1992; Newhouse, 1977). In other words, these studies have argued that the rise in health expenditures is a rational response to improving economic conditions, particularly the rise in per capita incomes. Following that, several studies have further argued that health spending rises more than one-for-one with income (Caporale *et al.*, 2018; Clemente *et al.*, 2004; Okunade and Karakus, 2001; Roberts, 1999).⁶³ Given this superior property of health goods and services, one can state that as per capita income rises, individuals will always devote an increasing share of their limited resources to health care (Hall and Jones, 2007). This last point gives rise to one of the most serious policy debates in recent years, especially in developed countries: the high costs of health care.

Figure 3 below shows per capita health expenditures over the period between 2000 and 2019 for two different groups of country aggregates: the developed and least developed parts of the world. According to the figures, one can argue that the underdeveloped part of the world could not take its share from these enormously rising health expenditures. In this sense, as of 2019, total per capita health expenditures were 5638.68 US dollars in high-income countries, 4947.71 US dollars in OECD members,

⁶³ An enormous number of studies have examined the elasticity puzzle between health expenditures and income. Following the seminal works of Kleiman (1974) and Newhouse (1977), the first strand of this line of research has examined the long-run income elasticity of health spending by using cross-sectional approaches for high-income countries (Culyer, 1989; Gerdtham *et al.*, 1992; Leu, 1986; Moore *et al.*, 1992; Parkin *et al.*, 1987) and for low- and middle-income countries (Gbesemete and Gerdtham, 1992; Van der Gaag and Stimac, 2008). As an extension to the first strand, several studies have focused on the time series properties of the variables in question and constituted the second strand of this research (Baltagi *et al.*, 2017; Baltagi and Moscone, 2010; Blomqvist and Carter, 1997; Clemente *et al.*, 2004; Dregers and Reimers, 2005; Freeman, 2012; Gerdtham and Löthgren, 2000; Hansen and King, 1996; Hartwig, 2008; Narayan, 2006). This line of research is out of the scope of this study.

and 3476.43 US dollars in the EU. However, they were just 42.82 US dollars in LDCs of the UN, 34.90 US dollars in low-income countries, and 79.43 US dollars in SSA countries in the same year. Of course, these figures are not surprising considering the persistent inequalities in income and health that have existed between developed and least-developed countries over the years. On the other hand, Figure 3 clearly demonstrates that different policy concerns arose among two different country groups regarding health care expenditures. In other words, in developed countries, the debate on health policy often focuses on limiting the growth of health spending given the high levels of population health outcomes achieved by these countries.⁶⁴ However, for LDCs, the policy agenda is much more complex. In these countries with a weak economic foundation, the debate usually focuses on efforts to meet and increase the resources devoted to health investments in order to improve the health status and capabilities of individuals while reducing the burden of health care costs.

Figure 3: Spending on Health by Country Aggregates



Source: WB, WDI (2022).

⁶⁴ According to the WDI of the WB (2022), in 2000, the life expectancy at birth was 77.46 in high-income countries, 77.08 in the EU, and 76.93 in OECD members, and in 2019, it rose to 80.89 in high-income countries, 81.31 in the EU, and 80.29 in OECD members. In parallel, the infant mortality rate was 6.50 in high-income countries, 5.88 in the EU, and 11.38 in OECD members in 2000, while it decreased to 4.20 in high-income countries, 3.29 in the EU, and 5.92 in OECD members as of 2019.

In more detail, in developed countries with better health outcomes, the evidence has suggested that rising health care expenditures are mostly led by increases in technical progress and in per capita income (Blomqvist and Carter, 1997; Fuchs, 1996; Hall and Jones, 2007; Newhouse, 1992; Nghiem and Connely, 2017; Okunade and Murthy, 2002; Moscone and Tosetti, 2010; Wanless, 2002). As health expenditures allow people to enjoy healthier and better lives, people value health spending more as their income rises. However, since each increase in health spending lowers the resources for other uses, a serious trade-off arises. Additionally, in these countries, increases in NCDs and long-term care due to aging further raise health care costs and preclude positive growth effects of health expenditures (Huber and Orosz, 2003; Lorenzoni *et al.*, 2019; OECD, 2016; OECD, 2020b; Van Zon and Muysken, 2001). Therefore, further increases in life span as experienced by high-income countries entail a serious trade-off between the size of the health care sector and growth prospects.

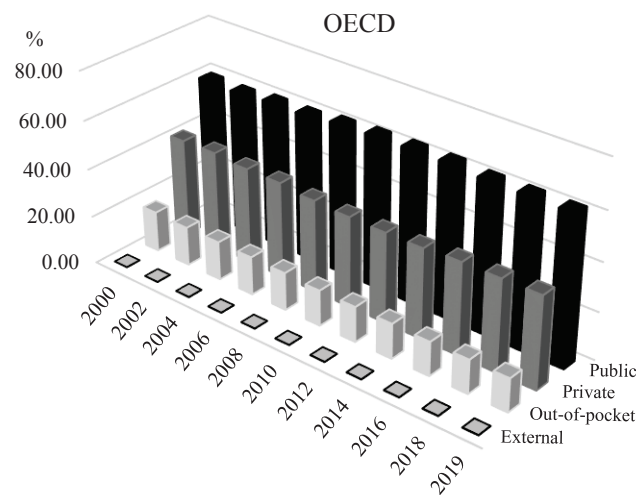
On the other hand, for countries with lower health activities, such as LDCs, a positive relationship is likely to exist between health care spending and income growth (Van Zon and Muysken, 2003). In other words, in LDCs with relatively poor health status, there is still more space that allows for further improvements in health outcomes⁶⁵, which in turn will boost economic growth through their positive impacts on human capital formation and labor productivity. Moreover, this resulting increase in income will further create more resources to spend both on health care and on achieving the objective of universal health coverage in these countries. However, familiar challenges prevent LDCs from creating enough resources to devote to health care. Therefore, in these countries, the trade-off is tighter than in their developed counterparts, given the low budgets of individuals and governments. This last sentence gives rise to another important issue—the financing sources of health care spending—which are obviously different in these two polar country groups.

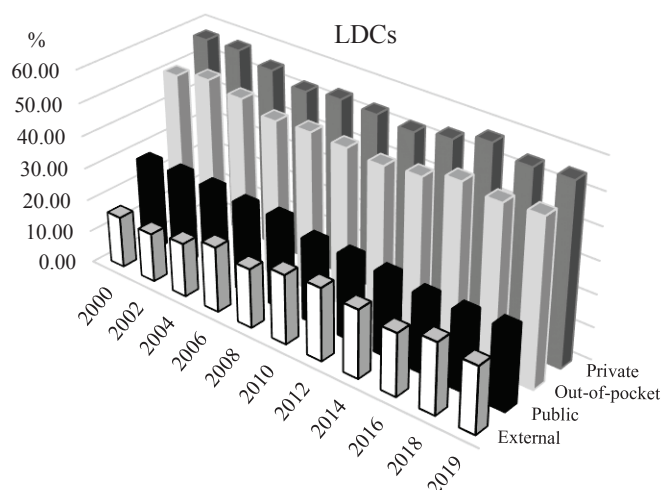
Diverging trends in the patterns of health care spending, as shown in Figure 3, also reflect the different patterns in which health care is financed across countries. The

⁶⁵ The life expectancy at birth was 55.48 in LDCs, 53.12 in low-income countries, and 50.45 in SSA countries in the year 2000, and as of 2019, it just became 65.34 in LDCs, 63.73 in low-income countries, and 61.63 in SSA countries. On the other hand, the infant mortality rate was 85.24 in LDCs, 89.20 in low-income countries, and 91.20 in SSA countries in 2000, while it decreased to 44.77 in LDCs, 48.20 in low-income countries, and 51.60 in SSA countries in 2019 (WB, 2022).

source of financing for health expenditures in a country is determined by the type of health care model adopted in that country. This further depends on the income levels of the countries and the debates over the equality and efficiency of these models. Following that, high-income countries mostly adopt a universal health care system that provides some access to basic health care goods and services for mostly all individuals in the country. In these countries, health care systems are usually financed through a mix of private and public contributions. For the former, funding sources include the contributions of households, corporations, and non-profit organizations, while taxation revenue is the main source of funding for the latter. Private expenditures are carried out through voluntary health insurance and direct payments to health care providers. On the other hand, most of the LDCs have a non-universal health care system, in which the vast majority of the population does not have full access to essential health care services. The health care systems in these countries mostly rely on private contributions and out-of-pocket payments by individuals.

Figure 4: Health Spending by Financing Source: OECD and LDCs





Source: WB, WDI (2022).

Following the above, Figure 4 shows the weight of health care expenditures in total health spending provided by different financing sources in two different country groups, OECD members and LDCs. The choice of the OECD is based on the fact that most of its members are classified as being in a developed or high-income country framework. According to the graph, health expenditures in OECD countries are primarily led by public and private health expenditures, while private expenditures and out-of-pocket payments by households are the main financing sources of the health care systems in LDCs. Furthermore, over the past two decades, the share of out-of-pocket expenditures on health was very low in OECD members, and the share of their external health expenditures was almost zero. On the other hand, for the same period, the share of public contributions in LDCs was poor and inadequate and almost the same as the share of external expenditures on health. In terms of 20-year averages, 61.23% of total health expenditures in OECD countries were provided by the public, 38.76% by private contributions, 15.13% by out-of-pocket payments of households, and 0.01% by external health expenditures. However, in LDCs, these averages were 26.19% for public spending, 54.86% for private spending, 49.92% for out-of-pocket payments, and 19.10% for external expenditures.

Figure 4 further reveals some of the following common points, even for the two different groups of countries given above. First, private expenditures on health, which include the payments of both individuals and non-governmental businesses, drive a large part of health spending in both country groups. Second, it is difficult for

the health care systems in LDCs to stay afloat without foreign transfers. Third, probably through distorting finance, governments bear most of the health care costs in OECD members in such a way that justifies serious public policy debates on ongoingly rising health care costs in high-income countries. On the other hand, it is households that bear most of the burden of health care costs in LDCs through private, personal, or out-of-pocket health spending. Heuristically speaking, this further means that individuals in LDCs suffer seriously from substituting non-health consumption in favor of increased health spending. However, increases in non-health consumption, which mainly includes consumption of housing, education, and other basic needs, are also as important as increases in life span for the welfare of individuals. In other words, one can argue that the former refers more to the quality of life, while the latter represents the quantity of life. Fourth, both public and household personal health expenditures continue to coexist in both country groups, even though they have adopted different health care and economic systems. Lastly, some amount of personal spending on health is always inevitable, even in the presence of large public contributions to health care, as in OECD countries. The last three points give rise to the theoretical work of this chapter as follows:

In an extended neoclassical growth framework, this chapter investigates the relationship between health expenditures and economic growth. Primarily, the chapter provides two augmented Ramsey models to examine the effects of personal and public health spending on capital accumulation, total income, and the welfare of households. Each Ramsey model assumes that personal health expenditures are inevitable and therefore enter the utility function of households by becoming a part of the endogenous trade-off between consumption and savings. The second model, on the other hand, extends the first model by incorporating tax-financed public health spending of the government into the felicity function of households. In other words, the second model considers endogenously determined public health expenditures, which are financed by a distortionary income tax on output. Therefore, in each model, both total personal consumption and total government spending are subject to a key distinction between health and non-health consumption. This distinction has significant implications for individuals' savings and clearly represents the trade-off between health and non-health consumption of individuals and the government.

Moreover, each Ramsey model considers the effects of positive externalities generated by health expenditures on the labor force. However, the first model presumes that it is the personal health spending of the households that generates this externality, while the second model considers the externality effect generated by the public. In each model, I further assume the existence of positive population and technological growth. The chapter directly focuses on long-run equilibria and provides the steady-state solutions of all model variables by using both market and social planner's solutions. In the absence of externalities, the two solutions coincide as each agent continues to consume, produce, and accumulate according to market prices. However, as several externalities and proportional income taxes are presented in each setup, the solution based on individual decision-making and the socially optimal solution become different in the study. Moreover, income taxes introduce inefficiencies due to their distortionary nature. Lastly, I provide a few extensions to the above models to make their findings somewhat comparable and to provide further implications on the effects of health expenditures.

The chapter further provides two more augmented Solow models in an effort to empirically test the effects of health expenditures provided by different financing sources on income growth and the convergence process. In this context, although the Ramsey framework allows for some quantitative analysis of convergence, it is not possible to develop an income convergence equation and obtain the estimated rate of convergence as in the Solow model. To that end, two augmented Solow models with the government are further derived in the study in order to run theory-backed income convergence regressions and estimate the growth effects of the model variables in question. As in Ramsey models, each Solow model considers the distinction between health and non-health consumption. That is, both models are derived by alternately highlighting the effects of personal and public expenditures on income growth. Furthermore, in parallel to the Ramsey models, the first model considers the externality effect of personal health expenditures on the production process, while the latter deals with the externality generated by public health spending. However, each model endogenizes personal and public health expenditures by assuming that they take a constant share from disposable and total income, respectively.

Following the augmented Solow models, the empirical part of the chapter provides dynamic panel data estimates of two theory-based convergence equations by employing a system GMM estimator. This approach corrects the analyses for a possible endogeneity, the omission of initial productivity, and the weak instrument problem. Moreover, the study examines the nexus between health spending and income growth for two polar country groups—OECD members and LDCs—which are quite different from each other in terms of their income levels and hence the health care models adopted. The empirical analyses include several indicators of health expenditures by the source of financing, from private to external health expenditures, to simultaneously consider the effects of different financing sources on income growth and the convergence process. Moreover, the income tax rate as a fiscal policy variable implied by the theoretical models and the human capital index and openness to trade as control variables are also included in the analyses in the study.

This chapter builds on the related literature in the following ways: First of all, extensive literature has emerged on the nexus between health expenditures and economic growth. However, health expenditures are both an input to produce health and a serious cost item in the budgets of all economic agents. Following that, the relationship between these two variables is always complex in its economic nature. Therefore, the available results on the link between health spending and growth are surprisingly erratic and still call for future research. In this sense, the study provided in this chapter differs from previous studies in terms of (i) the division made between consumption of health and non-health goods and services in utility, (ii) the simultaneous inclusion of both personal and public health spending in the felicity function instead of the level of health as in previous studies, and (iii) the externality defined in the production process. Another distinct feature of the approach used in this study is that the theoretical work in this chapter explicitly and endogenously considers the composition of public health spending. Although previous studies considered the impact of public health expenditures, only a few of them took into account the financing source of this spending. Each theoretical model in the chapter also answers the question of what determines the consumption expenditures of individuals and governments devoted to health care in a country.

Furthermore, to my best knowledge, there is no study in the related literature that explicitly models both personal and public health expenditures by using an extended Solovian framework. Earlier studies that used the same framework all focused on the stock of health in their theoretical parts instead of the flow of health expenditures. On the other hand, other empirical studies that have examined the link between health spending and growth have all run informal convergence regressions. Therefore, these two augmented Solow models developed in this chapter significantly contribute to the related literature by providing a theoretical background for formally testing income convergence conditional on the shares of personal and public health expenditures. Moreover, in each model, both personal and public health expenditures are endogenously defined as constant shares of output.

On the upshot, the work in this chapter fills an important gap in the related literature and represents the first attempt at formally inquiring into the link between health spending and growth by considering the financing agent of this spending. Lastly, the study further contributes to the related empirical research that examines the role of health spending on income growth and the convergence process by (i) employing a dynamic panel data approach with its superior features, (ii) using several indicators of health spending regarding different financing sources instead of total health expenditures used by previous studies, and (iii) including two quite different country groups in the analyses to compare and discuss their differences on this nexus with more recent data.

Some of the main findings of the chapter can be summarized as follows: First, the findings of the theoretical models show that both personal and public health expenditures grow at the rate of technological progress in the long run. Second, increases in personal and public health spending raise capital accumulation, the wage rate, and disposable income through their positive effects on labor productivity. However, in each case, an increase in income leads households to begin consuming more again. This leads to an increase in welfare but may raise concerns about both household and government budgets due to unavoidable increases in health spending. Third, the involvement of the government in the provision of health goods and services allows consumers to spend more on non-health goods and services and raises the share of non-health consumption in total consumption. Hence, under the assumption of gross

substitutability between health and non-health consumption, public health expenditures may help households establish a more balanced trade-off between the quantity of life and the quality of life.

Fourth, the existence of public health spending de-escalates the adverse impacts of income taxation on capital accumulation and disposable income. Moreover, in the framework of the Solow model, public health expenditures allow the savings rate to become free from the detractive effects of personal health spending. Fifth, of course, in each case, this favor of the government cuts down on public resources that could be used in other sectors of the economy where the government is engaged. Hence, while each resource used for health consumption is necessary to produce health, it simultaneously implies a serious and costly trade-off for both the consumers and the public. Especially in the absence of production externalities, each resource used for public health services directly lowers long-run capital accumulation and total output due to taxes and thereby puts pressure on the budgets of all actors in an economy. In this case, each resource used for personal health spending also directly lowers the quality of life for the consumers.

The empirical findings by country groups further indicate that private expenditures, which include the contributions of households, corporations, and non-profit organizations, significantly and positively relate to long-run income growth and the convergence process among OECD countries over a 20-year period. However, for this country group, the growth effects of public health spending are ambiguous and urgently call for future research. On the other hand, for LDCs, the findings show that health expenditures from all financing sources, even surprisingly external ones, have a negative effect on long-run economic growth. The findings further show that only out-of-pocket health expenditures by individuals positively contribute to income growth and the convergence process. These two findings on LDCs with scarce resources may imply that resources devoted to health care other than those of households do not contribute efficiently to the production of health capital, productivity improvements, and thus income growth. Moreover, the findings of the study show that all estimations provide support for absolute and faster conditional income convergence among OECD members. However, the findings indicate evidence of absolute and faster conditional income divergence among LDCs if one excludes the

effects of health expenditures from the regressions. Following that, controlling the impacts of health expenditures does not lead to any evidence of convergence or divergence among the sampled countries in the LDC group.

By combining theory and practice, this chapter has the following policy implications: The results of the study imply that health expenditures—personal or public—are inevitable in their nature to produce health, even though each of those is not cost- and hassle-free. Moreover, public support is always required to reduce the burden on individuals' budgets and provide them with a more balanced trade-off between quantity and quality of life. For OECD countries with better health outcomes and higher income levels, policy-makers should focus on planning the extent to which increased health spending in the future should be financed from private or public sources. The findings of the study do not directly impose a private or public option but highlight the significance of private contributions and question the efficiency of public spending on growth. The success of private contributions and competing demands for government resources may need to be seriously considered in the policy choice. Furthermore, given the serious concerns about government budgets caused by an increase in NCDs and population aging (OECD, 2016, 2021), it appears that increased pressure on public budgets will continue to be a serious health policy issue in OECD members in the near future. Therefore, as policy suggestions, (i) raising not the size but the efficiency of the health care sector and expenditures, (ii) increasing public awareness to promote healthier lifestyles and the use of preventative measures, and hence (iii) more efficient use of health care resources, may be useful to decelerate enormously rising health care expenditures in these countries.

In LDCs with poor health and economic status, policy-makers should seriously achieve the impossible by raising health expenditures to enhance health status and lowering the burdens on low individual and public budgets at the same time. Health is a direct component of both human capital and individuals' well-being. Therefore, in these countries, one can easily justify the need to increase spending on health to realize the potential of the human capital embodied in the population and to be productive at all. These efforts in turn will boost income growth with the size of the health care sector, in contrast to OECD members, for whom the issue is rather to prevent health expenditures from becoming a substitute for both growth and welfare prospects.

However, the findings of the study show that only individual efforts positively contribute to income growth in LDCs during the 20-year period, while the growth impacts of health expenditures provided by all other sources are negative. Surprisingly, even external aids, which are an integral part of the economic and health care systems of LDCs, negatively affect long-run growth.

Of course, raising public or external support for health spending is seriously required for the people in LDCs to lower the burden on their budgets. However, the findings of the study raise questions about the effective use of public and external resources. In other words, in these countries, both public and external health expenditures seem to have failed to realize their positive effects on growth through increases in health capital and productivity. However, in LDCs, there is a serious need for spending on health given their low health base and the existence of diseases such as HIV, tuberculosis, and malaria that still threaten the bulk of the population by causing disability and death (WHO, 2017). As a result, increasing public and external support for health spending by ensuring its effective use, particularly for those with the potential to increase productivity, may have an impact on LDCs, partially freeing up individual budgets and boosting long-run income growth through improvements in health status and labor productivity. Furthermore, imitating the success of OECD countries in private expenditures by providing the necessary infrastructure may also be helpful for LDCs. On the other hand, the findings of the study seriously call for future research on the effect and effectiveness of health expenditures in LDCs, as the findings significantly show that they are not capable of leading to sustainable income growth in the long run.

Furthermore, one more interesting finding from the study shows that the savings rate is quite high in LDCs as compared to OECD members and has a highly significant and positive impact on income growth in LDCs. Nevertheless, the findings also show that there is significant income divergence among LDCs. These findings may perhaps imply that investments are not being directed to the proper areas in these countries. As a result, to lower economic vulnerability and push the convergence, policy-makers in these countries may first direct capital investments in a more accurate and efficient manner, and then effectively use a portion of these investments as investments in health to promote population health. Otherwise, the long-run growth

prospects for these countries may virtually disappear as long as current practices continue to be implemented. Finally, both country groups have recently faced serious indirect effects of the COVID-19 pandemic, such as the sharp increases in total public and individual health spending (OECD, 2021; UN, 2020). Therefore, given these adverse effects of the ongoing pandemic, the burden and irrepressible increase of health expenditures, and hence the financing of health care, seem to continue to be critically on the agenda of policy-makers in both OECD members and LDCs, albeit from different perspectives.

The organization of this chapter is as follows: Section 2 provides a brief literature review of the related studies that examined the relationship between health expenditures and economic growth. Section 3 deals with two augmented Ramsey models, explains their solutions, and provides a few extensions to the models for comparison purposes. Section 4 develops two Solow models augmented with the health expenditures of different economic actors, presents their long-run solutions, and derives two convergence equations. Section 5 covers the empirical part of the chapter and explains the methodology, the sample data, and the empirical findings of the study. Finally, Section 6 concludes the chapter and provides some policy implications.

2.2. LITERATURE REVIEW

There has been an extensive body of literature focusing on the effects of health expenditures on economic growth. On the theoretical side, one branch of this literature was initiated by the study of Grossman (1972a, 1972b) and followed up by the studies of Muurinen (1982), Forster (1989), Ehrlich and Chuma (1990), Johansson and Löfgren (1995), and Meltzer (1997) in spirit. These studies have provided the first contributions to the optimal choice of health expenditures, consumption, and longevity. Over time, the research that follows these initial efforts has focused on the evolution of life expectancy and its interplay with economic growth by adopting a general equilibrium setting. All the studies from this background have highlighted different aspects of the nexus between health spending and growth by relying on different assumptions. In this sense, a few of them have attempted to explain the rise in health expenditures, especially by focusing on the trends in the U.S. (Cutler and

Richardson, 1997; Dalgaard and Strulik, 2014, 2017; Hall and Jones, 2007). Several works in the same tradition, on the other hand, have examined health expenditures as a cost of improving longevity by employing an overlapping generations framework. Most of them have considered the nexus between endogenous life expectancy, endogenous labor supply, consumption, and economic growth.⁶⁶

The studies that use an overlapping generations framework differ in their model settings, particularly whether endogenous lifetime is increased through private or public health spending. Some of these studies have argued that endogenous life expectancy can be improved by means of private health goods and services (Chakraborty and Das, 2000; Leung and Wang, 2010; Schneider and Winkler, 2021) or by specific public interventions (Aísa and Pueyo, 2006; Brembilla, 2016; Chakraborty, 2004; Fanti and Gori, 2014; Osang and Sarkar, 2008). On the other hand, some of them have accounted for the coexistence of private and public health spending by arguing that private and public health care systems often coexist in actual economies (Agénor, 2015; Bhattacharya and Qiao, 2007; Gori and Sodini, 2020; Kuhn and Prettnner, 2016; Varvarigos and Zakaria, 2013). The main distinction in their assumptions is based on whether young or old individuals benefit from private or public health investments. Although their results are not directly comparable due to different assumptions adopted in their model setups, most of these studies have shown that (i) countries usually spend more on health care as they prosper and (ii) savings and health expenditures compete for the same resources of an economy but complement each other in the long-run equilibrium.

Another branch has attempted to theoretically examine the link between economic growth and expenditures on health in a neoclassical growth framework. These studies are mostly related to the rapidly growing literature of human capital-based growth models, which have recognized health expenditures as the key source of health investments in health capital. For instance, the study of Barro (1996b) is among the first that theoretically emphasizes the role of health expenditures in an extended neoclassical setup. In his study, Barro (1996b) has developed several models to

⁶⁶ There were also others that have focused particularly on the demographic dynamics (Cervellati and Sunde, 2005, 2011, 2015; Galor and Moav, 2007; Galor and Weil, 2000; Kalemli-Ozcan, 2002; Prettnner, 2013) and on the optimal determination of retirement in the presence of longevity-enhancing health spending (Bloom *et al.*, 2014b; Kalemli-Ozcan and Weil, 2010; Kuhn *et al.*, 2015).

examine the interaction between health capital and economic growth, in which health expenditures are defined as a type of investment that allows individuals to accumulate health capital. In his first model, health capital is considered a private good that is financed only by households. In this model, health capital enters the production function as an input in addition to educational capital and directly raises the productivity of the labor force. According to the results of this extended model, increases in health capital directly lower the same depreciation rate for both education and health and indirectly increase the rate of return on both types of investments.⁶⁷ Another conclusion from his research showed that as the economy grows, both health and educational capital become relatively more important.

Barro (1996b) has further modified the above model by alternately ensuring that some portions of health services are regarded as publicly-subsidized private goods by means of (i) a rationed quantity and (ii) a price below the marginal cost. One important result from this type of modeling is that a higher income tax rate lowers the growth rates of consumption and marginal products for all three types of capital. Hence, when health services are financed by a proportional tax on output, this will lessen economic growth during the transitional period, the long-run equilibrium values of both physical and human capital, and the overall utility. Finally, in his study, Barro (1996b) defined health services as a pure public good and argued that the level of public health spending is determined by whether the government employs non-distorting or distorting tax finance.

Following a similar neoclassical framework, *i.e.*, an extended Ramsey (1928) framework, Muysken *et al.* (1999) have examined the optimal trade-off between health and consumption expenditures by formulating a healthy worker accumulation function instead of using a traditional health capital accumulation function. Their findings have shown that (i) an increase in the productivity of the health sector enhances the steady-state values of physical capital and healthy labor stock, (ii) if physical capital is scarce relative to the share of healthy workers, then optimal expenditures for health and consumption will be lower in the transitional period compared to their steady-state values but will eventually increase, and interestingly, (iii) in the long-run equilibrium,

⁶⁷ The point that an increase in health status reduces the depreciation rate of human capital and thereby increases the incentive for education investments was first stressed by Meltzer (1995).

per capita consumption raises the long-run share of healthy workers, and hence it is no longer negatively related to population growth.

In an endogenous growth framework, Van Zon and Muysken (1997, 2001) have extended the Lucas (1988) model to examine the relationship between longevity, welfare, and income growth. In their study, they have relied on two key assumptions: (i) good health or higher longevity is a necessary condition for individuals to provide labor, and (ii) the generation of health services is assumed to be a direct substitute for the generation of human capital in the form of education. According to their findings, good health status directly and positively affects the productivity of the workforce and the welfare of society. Their findings have further shown that increases in per capita income and longevity raise the demand for health services, which in turn leads to a slowdown in economic growth. In this sense, while the former implies an increase in economic growth, the latter indicates a decrease in growth due to a significant increase in health care costs.

In another study, Van Zon and Muysken (2003) extended the above model by considering (i) the effects of the changes in the rates of morbidity and mortality on long-run economic growth, (ii) a distinction between care and cure activities of health services, and (iii) a trade-off on the allocation of labor among health services, the final output sector, and human capital accumulation. Based on this setting, their results indicate a positive relationship between the health sector and income growth for low levels of health activities, but this relationship becomes negative as the level of health activities increases. In other words, their findings imply a positive relationship between the health sector and income growth in developing countries but a negative one in developed countries, which have experienced a significant increase in longevity over time.

In this context, the studies of Van Zon and Muysken (1997, 2001, 2003) have provided a dynamic version of Baumol's disease (1967), which highlights the trade-off between resources used in the health sector and in other sectors of an economy. In other words, as Grossman (1972a, 1972b) has stated, individuals incur health expenditures not only in sickness but also when they are healthy to maintain their good health status. Therefore, health status and health expenditures will always increase as income rises. However, as first noted by Baumol (1967), each resource used for health

investments exposes a direct trade-off between the health level of society and income growth. Particularly for developed countries, preferences for good health due to a rise in income and the aging of the population may lower physical capital investments and long-run income growth. Therefore, for these countries, there is a serious need to increase the productivity of the health sector instead of rashly raising health expenditures.

Following this argument, this feature of health expenditures has also been examined in other growth studies. For instance, following a Lucas-based (1988) production technology for human capital accumulation, Hosoya (2002) has investigated the relationship between economic growth, educational human capital, labor allocation, and longevity by assuming knowledge-driven technological change. The findings of the study have shown that good health is a necessary condition for long-term growth, while there exist two main trade-offs concerning (i) the nexus between consumption and health and (ii) the allocation of labor between the final goods, human capital, and health sectors. Similar to the findings of Van Zon and Muysken (2001, 2003), the results of the study have further shown that the inclusion of health status in an individual's welfare function raises the level of health services at the expense of economic growth, which in turn explains the possibility of a productivity slowdown due to an aging population in high-income countries. In the study, this finding was also supported by simple econometric tests for OECD countries.

In another study, Hosoya (2003) examined the impact of an exogenous government tax used to finance health expenditures by using a two-sector endogenous growth model. In the study, health capital accumulation is defined as a product of public health expenditures and capital deepening externality. The findings of the study have shown that higher capital deepening externality in health production lowers the tax rate required to maximize economic growth. This finding implies that some external effects, such as an improvement in living standards, have a considerable impact on health capital accumulation.⁶⁸

⁶⁸ In their studies, Barro (1996b), Hosoya (2002), and Van Zon and Muysken (1997, 2001, 2003) have examined the effects of human capital in the form of both health and education, while Gong *et al.* (2012), Hosoya (2003), Kelly (2017), and Muysken *et al.* (1999) have considered only the effects of human capital in the form of health.

Gong *et al.* (2012) have investigated the effects of health investments on welfare and income growth. By using an Arrow-Romer production function and a Grossman utility function, their study has concluded that an increase in health status seriously drives economic growth. However, the net effect of these rising health levels on growth depends on the relative sizes of the productivity effect of health status and the effect of health spending on physical capital. Therefore, if there is a continuous and rising trend in good health status of a country's population accompanied by rising health expenditures as the economy grows, then there may be a slowdown in the growth rate of per capita income in the long run. In their study, Gong *et al.* (2012) empirically tested their theoretical findings by using data from the provinces of China and concluded that their empirical findings are also consistent with their theoretical results.

Recently, Kelly (2017) has studied the nexus between health spending, health capital, public and private health insurance, and economic growth by assuming that health capital generates a positive externality effect on the final goods sector. The results of the study have shown that a one-time permanent productivity shock to the final goods sector or to the health sector positively affects total output, consumption of medical and non-medical goods, and aggregate welfare. After calibrating the model using data from the U.S. from 1996 to 2013, the results further show that a 10% increase in final goods productivity leads to a significant increase in income and consumption of medical goods, which in turn significantly improves the health stock of households and increases aggregate welfare. The findings have further indicated that increasing the share of private insurance in medical expenditures by 10% has much greater adverse effects on welfare than the same increase realized in the share of public expenditures.

On the other hand, there have been numerous studies that empirically investigate the relationship between health expenditures and growth. Following the seminal works of Kleiman (1974) and Newhouse (1977), an incredible part of this literature consists of the studies that examine the determinants of health expenditures and their elasticity with respect to total income. In this context, some of these studies have examined this relationship for developed countries (Culyer, 1989; Gerdtham *et al.*, 1992; Hitiris and Posnett, 1992; Leu, 1986; Moore *et al.*, 1992; Parkin *et al.*, 1987),

while others have focused on low-and middle-income countries (Bustamante and Shimoga, 2018; Farag *et al.*, 2012; Gbesemete and Gerdtham, 1992; Khan and Mahumud, 2015; Murthy and Okunade, 2009; Ke *et al.*, 2011). As a second part of this large literature, several studies have investigated the time series properties of the variables in question and have tested their unit root properties and the long-run cointegration relationships (Baltagi and Moscone, 2010; Baltagi *et al.*, 2017; Blomqvist and Carter, 1997; Chakroun, 2010; Dregers and Reimers, 2005; Freeman, 2012; Gerdtham and Löthgren, 2000; Hansen and King, 1996; Hartwig, 2008; Jewell *et al.*, 2003; Murthy and Ukpolo, 1994; Narayan, 2006; Okunade and Karakus, 2001; Moscone and Tosetti, 2010).

As an extension of this second part, others have examined whether there exists a causal relationship between the two variables (Amiri and Ventelou, 2012; Devlin and Hansen, 2001; Erdil and Yetkiner, 2009; Hartwig, 2010; Heshmati, 2001; Kumar, 2013; Rivera and Currais, 2003). On the other hand, by borrowing from the neoclassical theory of growth, the third part of this literature has focused on the cross-country differences in health expenditures following the initial work of Hitiris (1997). In this sense, in a cross-country framework, a number of studies have informally tested the hypotheses of absolute and conditional convergence in health expenditures (Alcalde-Unzu *et al.*, 2009; Aslan, 2008; Barros, 1998; Blazquez-Fernandez *et al.*, 2014; Hitiris and Nixon, 2001; Hofmarcher *et al.*, 2004; Kerem *et al.*, 2008; Leiter and Theurl, 2012; Montanari and Nelson, 2013; Nixon, 2000; Pekkurnaz, 2015; Villaverde *et al.*, 2014; Wang, 2009).

However, there have been only a limited number of studies that examine the effects of health expenditures on income growth and convergence dynamics using a Solow growth framework. In other words, there have been only a few studies that identify the role of health expenditures by deriving formal convergence regressions. In this sense, Rivera and Currais (1999a) have developed a theory-backed income convergence equation by embedding the traditional human capital accumulation function into an augmented Solow model. By using the share of total health expenditures in GDP as a proxy for the level of human capital, they have tested their income convergence equation for a cross-section of 24 OECD countries over the years between 1960 and 1990. Their empirical findings based on cross-sectional approaches

have shown that health expenditures have a significant and positive effect on income growth and the convergence process.

In another study, Rivera and Currais (1999b, 2003) also reported similar results for OECD countries by employing an IV estimation approach. Furthermore, using the same theoretical framework, Heshmati (2001) investigated conditional convergence in income and total per capita health expenditures for a panel of 22 OECD countries from 1970 to 1992. The findings of the study have indicated that total per capita health expenditures have a positive effect both on economic growth and on the speed of convergence. More recently, for 60 developing countries, Gaies (2022) has reported that per capita external health expenditures have no significant effect on income growth and the convergence process over the years between 2000 and 2017, while both per capita public and private health expenditures have a significant and positive effect.

Several studies have investigated the nexus between health expenditures and growth by employing *ad hoc* regressions. Some of these studies have focused on both OECD and low-income country groups. For instance, Gyimah-Brempong and Wilson (2004) have found that the share of total health expenditures in GDP has a positive effect on income growth and the convergence process among 22 OECD countries over the years between 1961 and 1995. In their study, they have also expanded the same empirical framework to include 21 SSA countries and estimated the same income growth equation over the years between 1975 and 1994. This time, by using the ratio of public health care expenditure to GDP, they have similarly found that the share of health expenditures has a positive effect on growth and the convergence process.

Moreover, Halıcı-Tülüce *et al.* (2016) examined the nexus between health expenditures and economic growth for 25 high-income countries over the years between 1995 and 2012 and also for 19 low-income countries from 1997 to 2009. For both low- and high-income countries, their findings have shown that private health expenditures have a significant and negative effect on economic growth, but the growth effects of public health expenditures are significant and positive. By focusing only on OECD countries, Beraldo *et al.* (2005) have examined the growth effects of health expenditures for the period between 1971 and 1998 and shown that both per capita public and private health expenditures significantly and positively affect income

growth, but the growth effects of public health expenditures are larger than those of private ones.

On the other hand, others have investigated the same relationship for developing countries, and particularly for African countries. In this sense, Baldacci *et al.* (2008) have found that the share of total health spending in GDP significantly and positively relates to income growth and the convergence process among 118 developing countries for the period between 1971 and 2000. In contrast to this, by estimating a simultaneous equations model, Dao (2012) has reported that income growth is negatively related to the growth of both per capita public health expenditures and the share of total health expenditures in GDP among 28 developing countries for the year 2005. Similar findings were reported by Eggoh *et al.* (2015). In their study, Eggoh *et al.* (2015) have shown that the share of total health expenditures in GDP has a negative impact on the growth rate of 49 African countries over the period from 1996 to 2010. Their results have further shown that there is evidence of significant income divergence among the sampled countries in Africa.

Furthermore, the findings of Aboubacar and Xu (2017) have revealed the existence of a positive and significant relationship between per capita total health expenditures and income growth among 36 SSA countries over the years between 1995 and 2014. However, they have found no evidence of income convergence among African countries. On the other hand, Bane (2018) demonstrated that total health expenditures had a positive and significant effect on growth and convergence processes among 52 low- and middle-income African countries from 1980 to 2015. More recently, Akinbode *et al.* (2021) have found that the share of total health expenditures in GDP has a positive and significant effect on income growth for 41 SSA countries during the years between 2000 and 2018, but there is significant divergence among the income growth rates of the sampled countries in the African region.

All in all, over the years, a fragmented and extensive literature has emerged on the nexus between health expenditures and economic growth. However, because health expenditures are both a significant part of health production and a significant cost for countries' health systems, the relationship between these two variables is always complex in its economic nature. Therefore, the results of the aforesaid studies

are surprisingly inconclusive and still call for future research. In this sense, this chapter investigates the relationship between health expenditures and income growth by providing four theoretical models and some empirical estimations as follows: First, the theoretical part of the chapter provides two augmented Ramsey models with technological progress and government. These two models examine the effects of health expenditures provided alternately by the households and the government on income growth, labor productivity, and total welfare.

In other words, the first model presumes that total health expenditures in an economy only include out-of-pocket expenditures of households, while the second assumes that out-of-pocket expenditures of households are supported by public health spending of the government. Each model assumes that both personal and public health expenditures enter the utility function and generate a positive externality on the firms' production process via an effective labor force. Hence, the first two models of this chapter differ from previous studies in terms of (i) their division between consumption of health and non-health goods and services, (ii) the simultaneous inclusion of both personal and public health expenditures in the utility function instead of the level of health, and (iii) the externality defined in the production function. Furthermore, the second model uses an endogenous definition of public health spending, which has been mostly ignored in previous studies that have considered the existence of lump-sum taxes.

On the other hand, the chapter provides two more augmented Solow models in an attempt to investigate the impact of both personal and public health spending on income growth and the convergence process. These two models are similar to those of the augmented Ramsey models in spirit but, of course, differ in several ways. In other words, as in Ramsey models, each Solow model considers the distinction between health and non-health consumption, the impacts of personal and public health spending on capital accumulation, productivity, and total income, and their externality effects on the total labor force. However, each is based on an exogenous consumption-savings trade-off, unlike Ramsey models. Moreover, each Solow model uses an endogenous definition of both personal and public health expenditures. In this context, to my best knowledge, there is no previous study in the related literature that endogenously and

separately models both personal and public health expenditures by using an extended Solovian framework.

Although a few studies have attempted to analyze the relationship between health spending and growth by using a formal Solow framework, these studies have all focused on the effects of health capital in their theoretical parts (Gaies, 2022; Heshmati, 2001; Rivera and Currais, 1999b). That is, they have considered the effects of the level of health in their theoretical models but proxied this health capital with total health expenditures in their empirical parts. Therefore, beyond their empirical contributions, these two augmented Solow models developed in this chapter significantly contribute to the related literature by providing (i) a theoretical background for using the variables related to personal and public health expenditures in conditional convergence analyses and (ii) further implications on the nexus between health spending and income growth.

Based on the above models, the empirical analyses in this chapter have the following distinctive characteristics: First, as mentioned above, only a few studies have offered a formal convergence regression to examine the role of health expenditures. However, these studies using formal regressions have all employed the same human capital accumulation equation in their theoretical parts instead of augmenting the Solow model by considering expenditures on health. Second, instead of employing cross-sectional or static panel data approaches as in previous studies, this study uses a dynamic panel data approach, the system GMM, to correct for a possible endogeneity, the omission of initial productivity, and the weak instrument problem. In this sense, although several studies have employed the same methodology by considering the above issues, they all come from informal origins and hence have preferred to use *ad hoc* regressions in their empirical analyses (Aboubacar and Xu, 2017; Akinbode *et al.*, 2021; Baldacci *et al.*, 2008; Bane, 2018; Beraldo *et al.*, 2005; Eggoh *et al.*, 2015; Halıcı-Tülüce *et al.*, 2016).

Following that, third, earlier studies have mostly used total measures of health expenditures in their empirical analyses without considering the source of financing. However, this study includes several indicators of health spending into the analyses—including various definitions of private, public, and external health expenditures—to simultaneously consider the effects of different financing sources on income growth

(not levels) and convergence. Fourth, different from earlier studies, this study examines the relationship between health expenditures and income growth for two separate country groups—OECD members and LDCs—to compare and discuss their differences on this nexus. Lastly, compared to previous studies, this study uses more recent data to examine the role of health spending on income growth and the convergence process.

2.3. TWO AUGMENTED RAMSEY MODELS: THE WELFARE AND PRODUCTIVITY EFFECTS OF HEALTH EXPENDITURES

Health expenditures are one of the main components of health investments and, hence, of human capital formation. They are broadly defined as expenditures on goods and services that allow an individual and society to maintain and improve their health status. In general, these expenditures include those on preventive and curative medical goods and services, on healthy food, and for adapting to a healthy lifestyle (*e.g.*, the cost of working out in the gym). Although they are critical to improving the health status of the population, enhancing workforce productivity, and increasing the quality and quantity of human capital, they also incur significant costs for country economies. In other words, while these expenditures form a large part of an economy's spending cycle, they also constitute a significant burden on the budgets of both individuals and governments.

In this chapter, the main focus of the study is to essentially show how consumption of health goods and services affects an economy in the long run, depending on the economic actor that bears the cost of these consumption expenditures. To this end, two different models are developed by using an extended Ramsey framework to examine the long-run implications of health expenditures on the welfare of society, on the productivity of the labor force, and hence on economic growth.⁶⁹ In this sense, the first model of the chapter assumes that all health

⁶⁹ This argument can be traced back to the studies of Arrow and Kurz (1970) and Arrow (1971), and in particular to the seminal work of Barro (1990), who was the first to use an endogenous growth framework to examine the effects of total government spending on output production and welfare. Following these seminal works, other notable extensions in this field include the studies of Boadway and Marchand (1995), Futagami *et al.* (1993), Greiner and Hanusch (1998), and Turnovsky (1996), among others.

expenditures in an economy are met by the out-of-pocket payments of consumers, while the second model assumes that the budget of the government gets involved in the provision of health goods and services. In other words, the first model presumes that all health expenditures in an economy are financed solely by households, while the latter assumes that these expenditures also include public health expenditures, which are financed by income taxes.

2.3.1. Personal Health Expenditures

The first model assumes that total health expenditures in the economy are financed by homogeneous households in such a way that more consumption of health goods and services lowers the consumption of other goods and services. In other words, in our hypothetical economy, each representative family dynasty obtains utility by consuming two different types of goods and services: health goods and services (C_{Ht}) and other consumer goods and services (C_{Ot}) (housing, education, electricity, and others). The consumption of health goods and services helps to maintain and enhance the good health status of individuals and is assumed to include consumption of all preventive and curative medical goods and services, healthy food, exercising in the gym, *etc.* The model further assumes that each household has L_t members and that the size of the household is determined by $L_t = L_0 \cdot e^{nt}$, where $n \geq 0$.⁷⁰ Furthermore, each member of the representative household inelastically supplies one unit of labor per time unit. That is, there is no trade-off between consumption and leisure in the model. As a result, each household maximizes the overall utility provided by $U(C_{Ht}, C_{Ot}) = \int_0^\infty u(c_{Ht}, c_{Ot}) \cdot L_t \cdot e^{-\rho t} \cdot dt$.

2.3.1.1. Households

The household's preferences are assumed to be represented by the following instantaneous utility function:⁷¹

⁷⁰ In the rest of the study, the number of people at the initial period is normalized to $L_0 = 1$.

⁷¹ It is assumed that each consumer will always buy some of each good.

$$u(c_{Ht}, c_{Ot}) = \int_0^\infty e^{-(\rho-n)t} \frac{((c_{Ht})^a (c_{Ot})^{1-a})^{1-\theta} - 1}{1-\theta} \cdot dt \quad (29)$$

where $u(c_{Ht}, c_{Ot})$ shows the instantaneous utility of the household obtained by consuming health and other goods and services, $c_{Ht} = \frac{C_{Ht}}{e^{nt}}$ denotes per capita consumption of health goods and services, and $c_{Ot} = \frac{C_{Ot}}{e^{nt}}$ is per capita consumption of other goods and services. The instantaneous utility function $u(c_{Ht}, c_{Ot})$ satisfies $u' > 0$ and $u'' < 0$ for each good, *i.e.*, positive but diminishing marginal utility. In Eq. (29), $\rho > 0$ is the subjective discount rate⁷², n is the exogenous growth rate of the household population, and the subindex t denotes time.^{73,74} a and $1 - a$ show the respective shares of both consumption goods ($0 < a < 1$) and θ technically refers to the curvature of the indifference curve for the two consecutive periods of time ($\theta > 0$).⁷⁵ Hence, the felicity function given above is also characterized by a constant relative risk aversion (CRRA) and a constant intertemporal elasticity of substitution (CIES).

Each household has a dynamic bookkeeping equation that shows the evolution of its total financial assets ($\dot{K}_t$). Total financial assets of the household are equal to total earnings minus consumption expenditures on health and other goods and services: $\dot{K}_t = r_t K_t + w_t L_t - c_{Ht} L_t - c_{Ot} L_t$, where K_t shows the household's total assets, r_t is the real interest rate, and w_t is the real wage rate.⁷⁶ Household income is further taxed by the government, which follows a balanced budget strategy. In this sense, the income tax ($\bar{\tau}$) is assumed to be a proportional levy on wage and private asset income. That is, $G_t = \bar{\tau}(rr_t k_t + w_t) = TAXR_t$, where G_t shows total government expenditures, $TAXR_t$ represents total government tax revenue, $0 < \bar{\tau} < 1$ shows the flat-rate of income tax, and rr_t denotes the rental rate of physical capital given the no-arbitrage condition. Of course, it is possible to differentiate the tax rates levied on capital income (τ_a) and on labor income (τ_w). However, as optimal taxation is beyond the main scope

⁷² Ramsey (1928) assumes $\rho = 0$ and argues that $\rho > 0$ is ethically indefensible (Ramsey, 1928: 543).

⁷³ Each variable with a subindex t is a function of time.

⁷⁴ $\rho - n > 0$ ensures the boundedness of the utility integral.

⁷⁵ For the case for which the felicity function includes only c_t , θ represents the Arrow (1965)-Pratt (1964) measure of the relative risk aversion or the elasticity of marginal utility, and $\frac{1}{\theta}$ is the elasticity of intertemporal substitution.

⁷⁶ A dot over a variable shows the time derivative of that variable.

of this chapter, I assume that $\tau_a = \tau_w = \bar{\tau}$ for simplicity purposes. Finally, combining the above assumptions with the No-Ponzi-Game (NPG) condition⁷⁷ provides the following dynamic budget constraint for each member of the household:

$$\dot{k}_t = (1 - \bar{\tau})(r_t k_t + w_t) - c_{Ht} - c_{Ot} - nk_t \quad (30)$$

In Eq. (30), $\dot{k}_t$ is the change in per capita assets of households over time and $k_t = \frac{K_t}{e^{nt}}$.

As a result, the household's decision problem is to choose a consumption-saving plan that maximizes utility while adhering to budget and NPG constraints.

$$\begin{aligned} \text{Max. } U(c_{Ht}, c_{Ot}) &= \int_0^\infty e^{-(\rho-n)t} \frac{((c_{Ht})^a (c_{Ot})^{1-a})^{1-\theta} - 1}{1-\theta} \cdot dt \\ \text{subject to (s. t.) } \dot{k}_t &= (1 - \bar{\tau})(r_t k_t + w_t) - c_{Ht} - c_{Ot} - nk_t \end{aligned} \quad (31)$$

The present-value Hamiltonian of this dynamic-optimization problem and the corresponding first-order conditions (FOCs) for a maximum of U are as follows:

$$J = e^{-(\rho-n)t} \frac{((c_{Ht})^a (c_{Ot})^{1-a})^{1-\theta} - 1}{1-\theta} + \xi_t \{ (1 - \bar{\tau})(r_t k_t + w_t) - c_{Ht} - c_{Ot} - nk_t \} \quad (32)$$

$$\frac{\partial J}{\partial c_{Ht}} = 0 \Rightarrow \frac{e^{-(\rho-n)t} a ((c_{Ht})^a (c_{Ot})^{1-a})^{1-\theta}}{c_{Ht}} = \xi_t \quad (33)$$

$$\frac{\partial J}{\partial c_{Ot}} = 0 \Rightarrow \frac{e^{-(\rho-n)t} (1-a) ((c_{Ht})^a (c_{Ot})^{1-a})^{1-\theta}}{c_{Ot}} = \xi_t \quad (34)$$

$$\dot{\xi}_t = -\frac{\partial J}{\partial k_t} \Rightarrow \dot{\xi}_t = -\xi_t \{ (1 - \bar{\tau})r_t - n \} \quad (35)$$

$$\dot{k}_t = \frac{\partial J}{\partial \xi_t} \Rightarrow \dot{k}_t = (1 - \bar{\tau})(r_t k_t + w_t) - c_{Ht} - c_{Ot} - nk_t \quad (36)$$

$$\lim_{t \rightarrow \infty} (\xi_t \cdot k_t) = 0 \quad (37)$$

⁷⁷ The NPG condition for households' per capita debt $\left(\lim_{t \rightarrow \infty} k_t e^{-\int_0^t (r_s - n) ds} \geq 0 \right)$ ensures that the growth rate of households' debt must be lower than r_t in the long run and rules out permanent financing of the interest payments by new loans.

where ξ_t represents the present-value shadow price of capital in terms of units of utils and Eq. (37) gives the transversality condition.

The FOC obtained in Eq. (35) shows that $\frac{\dot{\xi}_t}{\xi_t} = -\{(1 - \bar{\tau})r_t - n\}$. After log-linearization, if one follows the Keynes-Ramsey rule, then the Euler equations can be obtained by using Eqs. (33) and (34) as $\frac{\dot{c}_{Ht}}{c_{Ht}} = \left\{ (1 - \bar{\tau})r_t - \rho + (1 - a)(1 - \theta) \frac{\dot{c}_{Ot}}{c_{Ot}} \right\} \cdot \left(\frac{1}{1 - a + a\theta} \right)$ and $\frac{\dot{c}_{Ot}}{c_{Ot}} = \left\{ (1 - \bar{\tau})r_t - \rho + a(1 - \theta) \frac{\dot{c}_{Ht}}{c_{Ht}} \right\} \cdot \left(\frac{1}{a + \theta - a\theta} \right)$. From the ratio of Eqs. (33) and (34), one can also find that $c_{Ot} = \left(\frac{1-a}{a} \right) c_{Ht}$. Finally, the FOC given in Eq. (36) shows that $\dot{k}_t = (1 - \bar{\tau})(r_t k_t + w_t) - c_{Ht} - c_{Ot} - n k_t$.

2.3.1.2. Firms

On the production side, the model further presumes that the consumption of health goods and services enhances the productivity of the labor force. In this sense, there are several theoretical contributions in the literature, especially starting from the 1950s, that recognize and reveal the concept of “*productive consumption*” (Gersovitz, 1983, 1988; Nurkse, 1962; Steger, 2000, 2002; Wichmann, 1996). These studies have argued that total consumption does not only enhance the welfare of society but also the productivity of the labor force. Their results have further shown that productive consumption, mostly including nutrition, health, and education, increases the productive potential of the labor force (Steger, 2000: 365).

On the other hand, a number of empirical studies have found that these forms of consumption expenditures stimulate economic growth through their direct effects on labor performance (Fogel, 1994; Hicks, 1979; Strauss and Thomas, 1998; Wheeler, 1980). Given the literature above, in the model, it is assumed that the consumption of health goods and services enters the production function as a positive externality (E_t) that supports an effective labor force. In this sense, households’ consumption of health goods and services exactly generates a positive externality effect since firms would not take it into account when making decisions about their factor demands, and similarly, the households would not consider the effect of their consumption on the production process of the firms while choosing their consumption bundle. Thus, based

on the above assumption, the firms' production technology with CRS can be given as follows:

$$Y_t = K_t^\alpha \cdot (T_t \cdot L_t \cdot E_t)^{1-\alpha} \quad (28)$$

In Eq. (38), Y_t is the total output, K_t is the physical capital, and L_t is the total labor force/population.⁷⁸ α and $1 - \alpha$ represent the income shares of physical capital and total labor force, respectively, and $0 < \alpha < 1$. Each firm in the economy is assumed to have the same neoclassical CRS production function and Harrod-neutral technical progress. In this sense, $T_t = T_0 \cdot e^{\omega t}$ shows the level of technology and $\omega > 0$ is the exogenous growth rate of technological progress.⁷⁹ E_t depends on personal health consumption, which is assumed to generate a positive externality for the firms and increase labor productivity in a decreasing way. To put it another way, $E_t = (\check{c}_{Ht})^\gamma$, $\check{c}_{Ht} = c_{Ht} \cdot e^{-\omega t}$, $0 < \gamma < 1$, $E_t' > 0$, and $E_t'' < 0$. Given the production function above, the representative firm's flow of profits at any point in time can be given by

$$\pi_t = K_t^\alpha \cdot (T_t \cdot L_t \cdot E_t)^{1-\alpha} - w_t L_t - (r_t + \delta) K_t \quad (39)$$

where $\delta \geq 0$ is the depreciation rate of the physical capital. Hence, necessary and sufficient conditions for a competitive firm to maximize its profits produce the following results:⁸⁰

$$r_t = \alpha \check{k}_t^{\alpha-1} (\check{c}_{Ht})^{\gamma(1-\alpha)} - \delta \quad (30)$$

$$\check{w}_t = (1 - \alpha) \check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} \quad (41)$$

where $\check{y}_t = \check{k}_t^\alpha \cdot (\check{c}_{Ht})^{\gamma(1-\alpha)}$ is the intensive form of the production function, $\check{y}_t = \frac{Y_t}{T_t L_t}$,

$\check{k}_t = \frac{K_t}{T_t L_t}$, and $\check{w}_t = w_t \cdot e^{-\omega t}$ is the technology-adjusted real wage rate.

⁷⁸ Unlike in Chapter 1, in the rest of the study, the total workforce is assumed to be equal to the total population of a country.

⁷⁹ Following the related literature, in the study, the initial level of technology (T_0) is normalized to 1.

⁸⁰ The grave “ $\check{}$ ” on the variables shows that the variable is expressed in effective labor terms.

2.3.1.3. Market Equilibrium and Steady State

A simple transformation to effective labor terms and imposing the values of r_t and $\tilde{w}_t$ on the decentralized choices of the household provide the following equations of motion at the market equilibrium:

$$\frac{\dot{\check{c}}_{Ht}}{\check{c}_{Ht}} = \left\{ (1 - \bar{\tau})\alpha \check{k}_t^{\alpha-1} (\check{c}_{Ht})^{\gamma(1-\alpha)} - (\rho + \theta\omega + (1 - \bar{\tau})\delta) + (1 - a)(1 - \theta) \frac{\dot{\check{c}}_{Ot}}{\check{c}_{Ot}} \right\} \cdot \left(\frac{1}{1-a+a\theta} \right) \quad (42)$$

$$\frac{\dot{\check{c}}_{Ot}}{\check{c}_{Ot}} = \left\{ (1 - \bar{\tau})\alpha \check{k}_t^{\alpha-1} (\check{c}_{Ht})^{\gamma(1-\alpha)} - (\rho + \theta\omega + (1 - \bar{\tau})\delta) + a(1 - \theta) \frac{\dot{\check{c}}_{Ht}}{\check{c}_{Ht}} \right\} \cdot \left(\frac{1}{a+\theta-a\theta} \right) \quad (43)$$

$$\dot{\check{k}}_t = (1 - \bar{\tau})\check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} - \check{c}_{Ht} - \check{c}_{Ot} - (n + \omega + (1 - \bar{\tau})\delta)\check{k}_t \quad (44)$$

First, as usual, the consistency of equilibrium conditions with the existence of the steady state is checked before presenting the long-run equilibrium solutions of the model. To this end, from the ratio of Eqs. (33) and (34), it can be shown that $\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$ ⁸¹.

If the definition of steady state is used in $\frac{\dot{\xi}^s}{\xi^s} = -(1 - \bar{\tau})\alpha(\check{k}^s)^{\alpha-1}(\check{c}_H^s)^{\gamma(1-\alpha)} + (1 - \bar{\tau})\delta + n$, then one can obtain that $\frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$ and $\frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \gamma \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$ if $\frac{d}{dt} \left(\frac{\xi^s}{\xi^s} \right) = 0$. By assuming that $\frac{d}{dt} \left(\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} \right) = 0$ and $\frac{d}{dt} \left(\frac{\dot{\check{c}}_O^s}{\check{c}_O^s} \right) = 0$, the same results can also be obtained from

Eqs. (42) and (43). Similarly, if $\frac{d}{dt} \left(\frac{\dot{\check{k}}^s}{\check{k}^s} \right) = 0$ in Eq. (44), one can obtain that $(1 - \bar{\tau})(1 - \alpha)(\check{k}^s)^{\alpha-1}(\check{c}_H^s)^{\gamma(1-\alpha)} \left(-\frac{\dot{\check{k}}^s}{\check{k}^s} + \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} \right) = \left(\frac{\dot{\check{c}}_H^s}{\check{k}^s} - \frac{\dot{\check{k}}^s}{\check{k}^s} \frac{\check{c}_H^s}{\check{k}^s} \right) + \left(\frac{\dot{\check{c}}_O^s}{\check{k}^s} - \frac{\dot{\check{k}}^s}{\check{k}^s} \frac{\check{c}_O^s}{\check{k}^s} \right)$. Using

$\frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$ in the preceding expression yields $\left(\frac{\gamma(\check{c}_H^s + \check{c}_O^s) - \check{c}_H^s}{\check{c}_O^s} \right) \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$. Hence, according

to the above findings, it is obvious that $\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s} = \frac{\dot{\check{k}}^s}{\check{k}^s} = 0$ in the steady state.

⁸¹ The superscript s stands for defining the steady-state values of the variables.

The long-run equilibrium solution of the model is as follows: If $\frac{\dot{c}_H^s}{c_H^s} = \frac{\dot{c}_O^s}{c_O^s} = 0$ is used in Eq. (42) (or in Eq. (43)), then it can be shown that $\check{c}_H^s = \left(\frac{\rho+\theta\omega+(1-\bar{\tau})\delta}{(1-\bar{\tau})\alpha}\right)^{\frac{1}{\gamma(1-\alpha)}} (\check{k}^s)^{\frac{1}{\gamma}}$. Using $\frac{\dot{k}^s}{k^s} = 0$, $\check{c}_O^s = \left(\frac{1-a}{a}\right) \check{c}_H^s$, and the expression for $\check{c}_H^s$ in Eq. (44) gives the long-run equilibrium solution of effective capital per labor as

$$\check{k}^s = a^{\frac{\gamma}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{\gamma}{1-\gamma}} \quad (44)$$

Therefore, the long-run equilibrium values of physical capital and other model variables in per-worker terms can be given as follows:

$$k^s = a^{\frac{\gamma}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{\gamma}{1-\gamma}}. \quad (45)$$

$$T_0 \cdot e^{\omega t} y^s = a^{\frac{\gamma}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{\alpha+\gamma(1-\alpha)}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{\gamma}{1-\gamma}}. \quad (46)$$

$$T_0 \cdot e^{\omega t} c_H^s = a^{\frac{1}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{1}{1-\gamma}}. \quad (47)$$

$$T_0 \cdot e^{\omega t} c_O^s = (1-a) \cdot a^{\frac{\gamma}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{1}{(1-\alpha)(1-\gamma)}}. \quad (48)$$

$$\left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} s^s = \frac{\alpha(n+\omega+(1-\bar{\tau})\delta)}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \quad (9)$$

$$r^s = \frac{\rho+\theta\omega}{(1-\bar{\tau})} \quad (10)$$

$$w^s = (1-\alpha) \cdot a^{\frac{\gamma}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+(1-\bar{\tau})\delta}\right)^{\frac{\alpha+\gamma(1-\alpha)}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{\alpha}\right)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (11)$$

Eqs. (46)–(49) show that all per capita variables grow at the rate of technological progress in the long run. The findings given in Eqs. (51) and (52) further show that, as in the original Ramsey model with technological progress, the real interest rate approaches a constant value in the long run while the real wage rate grows at the rate of technological progress. The results of the comparative dynamic analysis also indicate that (i) the income tax rate has a negative effect on all long-run equilibrium values, (ii) increases in the rate of population growth (if one assumes $n > 0$) decrease the long-run equilibrium values of all model variables (except for the real interest rate), and (iii) the parameter a , which indicates the relative share of personal health consumption, has a positive effect on all per capita steady-state values of the variables given in Eqs. (46)–(49) and (52), except for the value of c_0^s .⁸²

The effect of the parameter a on the value of c_0^s depends on the relative magnitudes of γ and a . That is, $\frac{\partial c_0^s}{\partial a} > 0$ if $\gamma > a$ and $\frac{\partial c_0^s}{\partial a} < 0$ if $\gamma < a$. In this sense, the results further imply that in the long run, the value of a that maximizes the value of per capita consumption of other goods and services is equal to $a^* = \gamma$. This result clearly reflects the dual role of per capita health consumption on household utility and firms' production. In other words, in the model, personal health consumption has a direct and indirect effect on the total consumption of households. Increases in health consumption directly raise total consumption, but each increase in health consumption also lowers consumption of other goods and services, which may include housing, education, electricity, and other basic needs of households. On the other hand, increases in personal health consumption increase total consumption opportunities (including other goods and services) of households by raising the production output and, thus, disposable income. Therefore, the net effect of a on c_0^s depends on the relative magnitudes of γ and a . Of course, in the absence of an externality, increases in a will directly decrease the consumption of other goods and services.

Last but not least, given the long-run equilibrium savings rate in Eq. (50), one can show that as long as $\alpha(n + \omega + (1 - \bar{\tau})\delta) < (\rho + \theta\omega + (1 - \bar{\tau})\delta)$ holds, the equilibrium savings rate is lower than one ($s^s < 1$). Furthermore, it can be shown that

⁸² Note that the parameter restriction $\rho - n > (1 - \theta)\omega$ holds in each case for the boundedness of the utility integral. This restriction also implies that $(\rho + \theta\omega + (1 - \bar{\tau})\delta) > \alpha(n + \omega + (1 - \bar{\tau})\delta)$. The model further requires that $a < \frac{1}{1-\theta}$.

the long-run savings rate is negatively affected by an increase in consumption smoothing $\frac{\partial s^s}{\partial \theta} < 0$, in the rate of impatience $\frac{\partial s^s}{\partial \rho} < 0$, and in the income tax rate $\frac{\partial s^s}{\partial \bar{\tau}} < 0$, but it is positively affected by an increase in the rate of population growth $\frac{\partial s^s}{\partial n} > 0$, in the depreciation rate of physical capital $\frac{\partial s^s}{\partial \delta} > 0$, and in the elasticity of output with respect to physical capital $\frac{\partial s^s}{\partial \alpha} > 0$. Appendix 2 further provides the centralized solution of the model, which assumes that all decisions in the economy are made by a benevolent, powerful, and all-knowing central authority. This central planner has the same preferences as those of the representative household but is subject to the aggregate resource constraints of the economy. Hence, this central planner makes all economic decisions for the benefit of all and dictates its choices by explicitly taking the positive externality of health consumption into account, unlike the independent and competitive actors of the market. Therefore, this central planner, who can be regarded as a social planner with dictatorial powers, will always obtain the economy's first-best outcomes and attain a Pareto optimum. In this sense, note that the equilibrium savings rate given in Eq. (A32) is not affected by the existence of the income tax rate.

Finally, one can provide the following long-run ratios on health expenditures by considering two different approaches followed for the solution of the model. In this context, Eq. (53) below gives the ratio of per capita health expenditures to real per capita income by using the results from the competitive solution (CS), and Eq. (54) provides the same ratio by following the solution of the social planner (SPS).

$$\left(\frac{c_H^s}{y^s}\right)^{CS} = a \left(\frac{(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right) \quad (53)$$

$$\left(\frac{c_H^s}{y^s}\right)^{SPS} = (1 - \bar{\tau}) \left(\frac{a[(\rho+\theta\omega+\delta)-\alpha(n+\omega+\delta)]+(1-a)(1-\alpha)\gamma(\rho+\theta\omega+\delta)}{(\rho+\theta\omega+\delta)} \right) \quad (54)$$

Eqs. (53) and (54) demonstrate that $\frac{\partial \left(\frac{c_H^s}{y^s}\right)}{\partial \rho} > 0$, $\frac{\partial \left(\frac{c_H^s}{y^s}\right)}{\partial \alpha} < 0$, and $\frac{\partial \left(\frac{c_H^s}{y^s}\right)}{\partial \bar{\tau}} < 0$. In other words, the share of personal health expenditures in total income is positively affected by an increase in the rate of impatience but negatively affected by an increase in the share of physical capital and a decrease in disposable income via an increase in the

income tax rate. On the other hand, as expected, the ratio in Eq. (53) indicates that the relative share of personal health expenditures has a positive effect on the personal

health spending-income ratio, *i.e.*, $\frac{\partial \left(\frac{c_H^s}{y^s} \right)^{CS}}{\partial a} > 0$. However, Eq. (54), which explicitly

reflects the effect of the externality, shows that $\frac{\partial \left(\frac{c_H^s}{y^s} \right)^{SPS}}{\partial a} > 0$ if $(1 - (1 - \alpha)\gamma) >$

$\frac{\alpha(n+\omega+\delta)}{(\rho+\theta\omega+\delta)}$. In other words, $\frac{\partial \left(\frac{c_H^s}{y^s} \right)^{SPS}}{\partial a} > 0$ if the share of personal health consumption (in effective labor terms) in total production is lower than the MPC, $(1 - s^s) > (1 - \alpha)\gamma$.

Eq. (54) further indicates that $\frac{\partial \left(\frac{c_H^s}{y^s} \right)^{SPS}}{\partial \gamma} > 0$. That is, all else being equal, an increase in γ leads to an increase in both total and disposable income in the economy. However, at the end of the day, the increase in γ causes a larger increase in personal health expenditures compared to the increase in total income.

2.3.2. Public Health Expenditures

In most countries, the burden of health expenditures largely falls on the government.⁸³ To reflect this fact, three new assumptions have been added to the above model. First, this second model assumes that total health expenditures in an economy consist of public health expenditures, which are further financed by a proportional tax on household earnings. In this sense, the second model assumes that the representative government collects income taxes at a flat rate $\bar{\tau}$ and spends a constant share (x_H) of this tax revenue on public health goods and services by following a balanced-budget strategy, *i.e.*, $G_t = \bar{\tau}(rr_t k_t + w_t) = TAXR_t$. In other words, total government expenditures (G_t) that are financed by total tax revenues ($TAXR_t$) are further divided

⁸³ Of course, the size of the burden depends on the health care model of a country. That is, it depends on whether the country in question has a universal government-funded health system (the Beveridge model), a social health insurance system (the Bismarck model), a single-payer national health insurance system (the National Health Insurance model), or a market-driven health care system (the out-of-pocket model). In fact, most countries have a mix of these models, while LDCs with few resources generally have a market-driven health care system and high-income countries generally rely on the Beveridge or Bismarck models. For now, this chapter excludes the discussion of the major types of health care systems. Nevertheless, one can argue that the first model of the chapter may be considered in the framework of a market-driven health care system, in which all health expenditures are financed only by the consumers.

between public expenditures on health (G_{Ht}) and public expenditures on other goods and services (G_{Ot}) ($G_t = G_{Ht} + G_{Ot}$). Hence, in the model, total government health expenditures are defined as $G_{Ht} = x_H G_t = x_H \bar{r}(r r_t k_t + w_t)$ and $0 < x_H < 1$, which further implies that $G_{Ot} = (1 - x_H) G_t = (1 - x_H) \bar{r}(r r_t k_t + w_t)$.

Second, the model presumes that the representative household obtains utility by consuming private goods and services (C_t) and public health goods and services (G_{Ht}). Compared to the first model, this model assumes that consumption of private goods and services includes households' consumption of other goods and services (represented by C_{Ot} in the first model) and personal expenditures on healthy food, sports, and others (C_{Ht} in the first model). This assumption is based on the fact that in most health systems, public health expenditures cover only the costs of medical goods and services such as medical examinations, checkups, hospital services, and medication. In this sense, one may also consider other public goods and services, such as green areas, free outdoor gyms and fitness equipment, and bicycle and walking paths, within the scope of health-enhancing services provided by the public to cope with the risk of various diseases and health problems. However, if personal health expenditures are broadly defined to include expenditures for a healthy diet and even for a healthy lifestyle, then personal health consumption is always unavoidable and never vanishes, even when the government provides some public health goods and services to each individual.

Furthermore, sometimes the public provides generic drugs instead of brand-name drugs. In these cases, individuals can even spend on medicine if they have an income advantage that will enable them to not prefer generic drugs provided by the public. In short, in this second model, it is assumed that government health expenditures finance some health goods and services—mostly medical ones—that enter households' utility functions. The representative household is assumed to derive positive utility from consuming both private goods and services and public health goods and services by taking the time path of public health goods and services as given. Based on these additional assumptions, the total utility function of the representative household can be given by $U(c_t, g_{Ht}) = \int_0^\infty u(c_t, g_{Ht}) \cdot L_t \cdot e^{-\rho t} \cdot dt$, where $c_t = \frac{C_t}{e^{nt}}$ is per capita private consumption and $g_{Ht} = \frac{G_{Ht}}{e^{nt}}$ gives per capita consumption of

public health goods and services provided by the government as a constant share of total public spending. Therefore, the instantaneous utility function in per capita terms

is defined as $u(c_t, g_{Ht}) = \frac{((c_t)^a (g_{Ht})^{1-a})^{1-\theta} - 1}{1-\theta}$.⁸⁴

2.3.2.1. Households

Given the above assumptions and the NPG condition, the household decision problem can be represented by

$$\begin{aligned} \text{Max. } U(\check{c}_t, \check{g}_{Ht}) &= \int_0^\infty e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} ((\check{c}_t)^a (\check{g}_{Ht})^{1-a})^{1-\theta} - 1}{1-\theta} \cdot dt \\ \text{s.t. } \dot{\check{k}}_t &= (1 - \bar{\tau})(r_t \check{k}_t + \check{w}_t) - \check{c}_t - (n + \omega) \check{k}_t \end{aligned} \quad (55)$$

and the corresponding present-value Hamiltonian and FOCs for a maximum of U are given by

$$J = e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} ((\check{c}_t)^a (\check{g}_{Ht})^{1-a})^{1-\theta} - 1}{1-\theta} + \xi_t \{ (1 - \bar{\tau})(r_t \check{k}_t + \check{w}_t) - \check{c}_t - (n + \omega) \check{k}_t \} \quad (56)$$

$$\frac{\partial J}{\partial \check{c}_t} = 0 \Rightarrow \frac{e^{-(\rho-n)t} e^{(1-\theta)\omega t} a ((\check{c}_t)^a (\check{g}_{Ht})^{1-a})^{1-\theta}}{\check{c}_t} = \xi_t \quad (57)$$

$$\dot{\xi}_t = -\frac{\partial J}{\partial \check{k}_t} \Rightarrow \dot{\xi}_t = -\xi_t \{ (1 - \bar{\tau})r_t - n - \omega \} \quad (58)$$

$$\dot{\check{k}}_t = \frac{\partial J}{\partial \xi_t} \Rightarrow \dot{\check{k}}_t = (1 - \bar{\tau})(r_t \check{k}_t + \check{w}_t) - \check{c}_t - (n + \omega) \check{k}_t \quad (59)$$

Additionally, the transversality condition is $\lim_{t \rightarrow \infty} (\xi_t \cdot \check{k}_t) = 0$. The first two FOCs of the household's decentralized choices provide the Euler equation as $\frac{\dot{\xi}_t}{\xi_t} =$

⁸⁴ The definitions of all other parameters and variables were already provided in the first model of this section.

$\left\{ (1 - \bar{\tau})r_t - \rho - \theta\omega + (1 - a)(1 - \theta)\frac{\dot{g}_{Ht}}{g_{Ht}} \right\} \cdot \left(\frac{1}{1 - a + a\theta} \right)$. Eq. (59) further shows that $\dot{k}_t = (1 - \bar{\tau})(r_t \check{k}_t + \check{w}_t) - \check{c}_t - (n + \omega)\check{k}_t$.⁸⁵

2.3.2.2. Firms

On the production side, the second model continues to assume that the consumption of health goods and services supports the productivity of the labor force, but this time, these productivity-supporting health goods and services are provided by the government. In this model, the reason I assume that all the externality is generated by the public goods and services is based on a basic economic argument that justifies the government's intervention in the economy. As the market cannot provide public goods and services and handle externalities, public intervention can lead to more positive outcomes in cases where there are opportunities for positive externalities. Therefore, the variable E_t in the first model is now assumed to be a function of public health expenditures. That is to say, $E_t = (\check{g}_{Ht})^\gamma$, $\check{g}_{Ht} = g_{Ht} \cdot e^{-\omega t}$, and $0 < \gamma < 1$. In their production processes, all firms in the economy benefit from these public health goods and services provided by the government free of charge. In this context, the aggregate production function can be given as in the first model, $Y_t = K_t^\alpha \cdot (T_t \cdot L_t \cdot E_t)^{1-\alpha}$, but the production function in effective worker terms is now defined as

$$\check{y}_t = \check{k}_t^\alpha \cdot (\check{g}_{Ht})^{\gamma(1-\alpha)} \quad (60)$$

Hence, the profit-maximizing conditions for a competitive firm provide the following results:

$$r_t = \alpha \check{k}_t^{\alpha-1} (\check{g}_{Ht})^{\gamma(1-\alpha)} - \delta \quad (61)$$

$$\check{w}_t = (1 - \alpha) \check{k}_t^\alpha (\check{g}_{Ht})^{\gamma(1-\alpha)} \quad (62)$$

⁸⁵ Of course, from the viewpoint of a social planner, the story will be different. In other words, a social planner knows that $g_{Ht} = x_H \bar{\tau} y_t$ from the very beginning and decides differently. The solution to the social planner is provided in Appendix 3.

2.3.2.3. Market Equilibrium and Steady State

As before, if the values of r_t and $\tilde{w}_t$ given in Eqs. (61) and (62) are used in FOCs obtained from the household's problem, one can obtain that $\frac{\dot{c}_t}{c_t} = \left\{ (1 - \bar{\tau})\alpha\tilde{k}_t^{\alpha-1}(\tilde{g}_{Ht})^{\gamma(1-\alpha)} - (\rho + \theta\omega + (1 - \bar{\tau})\delta) + (1 - a)(1 - \theta)\frac{\dot{\tilde{g}}_{Ht}}{\tilde{g}_{Ht}} \right\} \cdot \left(\frac{1}{1-a+a\theta} \right)$ and $\dot{\tilde{k}}_t = (1 - \bar{\tau})\tilde{k}_t^\alpha(\tilde{g}_{Ht})^{\gamma(1-\alpha)} - \tilde{c}_t - (n + \omega + (1 - \bar{\tau})\delta)\tilde{k}_t$. Using the exogenous definition of $\tilde{g}_{Ht} = \tilde{k}_t^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}}$ and assuming the existence of the steady state in the above equations further provide that at the steady state, $\dot{\tilde{k}}^s = \dot{\tilde{c}}^s = \dot{\tilde{y}}^s = \dot{\tilde{g}}_H^s = 0$, given the non-negativity constraints of the model variables.

Therefore, following these findings, one can show that $\tilde{k}^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}}$ if $\frac{\dot{c}^s}{c^s} = 0$ and $\tilde{g}_H^s = (\tilde{k}^s)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}}$. Finally, using the value of $\tilde{k}^s$ in $\frac{\dot{\tilde{k}}^s}{\tilde{k}^s} = (1 - \bar{\tau})(\tilde{k}^s)^{\frac{-(1-\alpha)(1-\gamma)}{1-\gamma+\alpha\gamma}} \cdot (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - \frac{\tilde{c}^s}{\tilde{k}^s} - (n + \omega + (1 - \bar{\tau})\delta)$ easily provides that $\tilde{c}^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta) - \alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}}$, given that $\frac{\dot{\tilde{k}}^s}{\tilde{k}^s} = 0$. As a result, the long-run equilibrium values of per capita variables are obtained as follows:

$$k^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t} \quad (63)$$

$$c^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta) - \alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t} \quad (64)$$

$$y^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t} \quad (65)$$

$$g_H^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{1}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t} \quad (66)$$

Based on the preceding results, the long-run equilibrium values of other public variables can be given by

$$g^s = tax r^s = \bar{\tau}^{\frac{1}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (67)$$

$$g_O^s = (1 - x_H) \cdot \bar{\tau}^{\frac{1}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (68)$$

and the steady-state values of the real interest rate, the real wage rate, and the savings rate are obtained as follows:

$$r^s = \frac{\rho+\theta\omega}{(1-\tau)} \quad (69)$$

$$w^s = (1 - \alpha) \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (70)$$

$$s^s = \frac{\alpha(n+\omega+(1-\bar{\tau})\delta)}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \quad (71)$$

Eqs. (63)–(68) show that all per capita variables in the model grow at the rate of technological progress in the long-run equilibrium. Similar to the findings of the first model, Eqs. (69)–(70) indicate that at long-run equilibrium, the real interest rate approaches a constant value while the real wage rate grows at the rate of ω . The findings in Eqs. (63)–(67) and (70) further show that an increase in the share of public health expenditures in total public expenditures (x_H) raises all steady-state values of the variables. However, Eq. (68) indicates that increases in x_H raise the value of other public goods and services if $\gamma > x_H$. That is, $\frac{\partial g_O^s}{\partial x_H} > 0$ if $\gamma > x_H$ and $\frac{\partial g_O^s}{\partial x_H} < 0$ if $\gamma < x_H$.⁸⁶ This finding also implies that the value of x_H that maximizes the value of public expenditures on other goods and services is equal to $x_H^* = \gamma$ in the long run.

Unlike the first model, in this model, the net effect of the income tax rate on the steady-state values of capital and income per worker depends on some parameter restrictions. That is, $\frac{\partial k^s}{\partial \bar{\tau}} < 0$ if $\left(\frac{1-\gamma(1-\alpha)}{1-\alpha} \right) \left(\frac{\rho+\theta\omega}{\rho+\theta\omega+(1-\bar{\tau})\delta} \right) > \frac{\gamma(1-\bar{\tau})}{\bar{\tau}}$ and $\frac{\partial y^s}{\partial \bar{\tau}} < 0$ if $\left(\frac{\alpha}{1-\alpha} \right) \left(\frac{\rho+\theta\omega}{\rho+\theta\omega+(1-\bar{\tau})\delta} \right) > \frac{\gamma(1-\bar{\tau})}{\bar{\tau}}$. On the other hand, similar to the first model, the results

⁸⁶ Note that the restrictions $\rho - n > (1 - \theta)\omega$ for the boundedness of the utility integral and also $(\rho + \theta\omega + (1 - \bar{\tau})\delta) > \alpha(n + \omega + (1 - \bar{\tau})\delta)$ hold in each case. The model further requires that $a < \frac{1}{1-\theta}$ and $\frac{1}{1-\alpha} > \gamma$.

further show that the long-run savings rate in Eq. (71) is a negative function of consumption smoothing $\frac{\partial s^s}{\partial \theta} < 0$, the rate of impatience $\frac{\partial s^s}{\partial \rho} < 0$, and the income tax rate $\frac{\partial s^s}{\partial \tau} < 0$, but it is a positive function of the population growth rate $\frac{\partial s^s}{\partial n} > 0$, the depreciation rate of the physical capital $\frac{\partial s^s}{\partial \delta} > 0$, and the elasticity of output with respect to physical capital $\frac{\partial s^s}{\partial \alpha} > 0$. Additionally, Eq. (A44) in Appendix 3, which provides the centralized solution of the model, indicates that $\frac{\partial s^s}{\partial \theta} < 0$, $\frac{\partial s^s}{\partial \rho} < 0$, $\frac{\partial s^s}{\partial n} > 0$, $\frac{\partial s^s}{\partial \delta} > 0$, $\frac{\partial s^s}{\partial \alpha} > 0$, and $\frac{\partial s^s}{\partial \gamma} > 0$.

2.3.3. A Small Supplement to the Models

The above two subsections provide two extended Ramsey models that differ in terms of the source that generates positive externality in the production process. In this sense, the first model highlights the effects of personal health consumption, while the second model abandons the assumptions of the first and concerns the externality imposed by public health expenditures both on the well-being of the individual agent and on production. At this point, to make the results of the two models somewhat comparable⁸⁷, it would be more appropriate to modify (i) the second model to include the distinction between personal consumption of health and other goods and services and (ii) both models by excluding production externalities. That is, first, let us assume that the households maximize the following utility function, subject to the same constraints as the second model given in Eq. (55).

$$U(\check{c}_{Ht}, \check{c}_{Ot}, \check{g}_{Ht}) = \int_0^\infty e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} \left(((\check{c}_{Ht})^\psi (\check{g}_{Ht})^{1-\psi})^a (\check{c}_{Ot})^{1-a} \right)^{1-\theta} - 1}{1-\theta} \cdot dt \quad (72)$$

Given the above utility function, one can easily show that at long-run equilibrium, per capita values of physical capital, income, and total consumption are

⁸⁷ Because the results in other cases are dependent on the relative magnitudes of four unknown parameters indicating the shares of expenditures: a , x_H , $\bar{\tau}$, and ψ .

the same as those in the second model. That is, $k^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}}$. $(x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t}$, $y^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t}$, and $\check{c}^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot T_0 \cdot e^{\omega t}$. This setting allows for obtaining the long-run values of c_{Ht} and c_{Ot} but does not change the findings on the long-run values of other model variables. On the other hand, the long-run values of per capita consumption of health and other goods and services are obtained as follows:

$$c_H^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot \left(\frac{a\psi}{1-a(1-\psi)} \right) \cdot T_0 \cdot e^{\omega t} \quad (73)$$

$$c_O^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{(1-\gamma)}} \cdot \left(\frac{1-a}{1-a(1-\psi)} \right) \cdot T_0 \cdot e^{\omega t} \quad (74)$$

Eqs. (73) and (74) show that an increase in the relative share of public health expenditures both in utility and in total public spending raises per capita personal consumption of both health and other goods and services. That is, $\frac{\partial c_H^s}{\partial (1-\psi)} > 0$ and $\frac{\partial c_O^s}{\partial (1-\psi)} > 0$ and $\frac{\partial c_H^s}{\partial x_H} > 0$ and $\frac{\partial c_O^s}{\partial x_H} > 0$. It can also be demonstrated that $\frac{\partial c_H^s}{\partial \psi} > 0$ and $\frac{\partial c_O^s}{\partial \psi} < 0$. Therefore, while an increase in the weight of personal health spending decreases the consumption of other goods and services, an increase in public health spending raises both components of consumption through its positive effects on both utility and production output. An increase in public health spending (i) allows households to have more spaces for both components of their total consumption and (ii) leads to an increase in total output, which further raises disposable income and, hence, the total consumption possibilities of the households. Parallel to these, Eqs. (48) and (49) indicate that an increase in the income tax rate decreases the long-run values of per capita consumption of both health and other goods and services in the first

model. However, this negative effect is limited in the second model since public health expenditures are fed only by these taxes in the model, *i.e.*, Eqs. (73) and (74) show that

$$\frac{\partial c_H^s}{\partial \bar{\tau}} < 0 \quad \text{and} \quad \frac{\partial c_O^s}{\partial \bar{\tau}} < 0 \quad \text{only if} \quad \left(\frac{1-\gamma(1-\alpha)}{(1-\alpha)(1-\gamma)} \right) \left(\frac{\rho+\theta\omega}{(1-\bar{\tau})(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right) + \frac{\delta(1-\alpha)}{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)} > \frac{\gamma}{(1-\gamma)\bar{\tau}}.$$

Secondly, if the production externalities are excluded from both models, one can obtain the following long-run solutions: For the first model with personal health expenditures, the results at the steady state are obtained as

$$k^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (75)$$

$$y^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (76)$$

$$c_H^s = a \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot T_0 \cdot e^{\omega t} \quad (77)$$

$$c_O^s = (1-a) \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot T_0 \cdot e^{\omega t} \quad (78)$$

$$c^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot T_0 \cdot e^{\omega t} \quad (79)$$

$$g^s = \text{tax}r^s = \bar{\tau} \cdot \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (80)$$

and for the second model that considers both personal and public health expenditures, the steady-state solutions provide the following results:

$$k^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (81)$$

$$y^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (82)$$

$$c_H^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot \left(\frac{a\psi}{1-a(1-\psi)} \right) \cdot T_0 \cdot e^{\omega t} \quad (83)$$

$$c_O^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot \left(\frac{1-a}{1-a(1-\psi)} \right) \cdot T_0 \cdot e^{\omega t} \quad (84)$$

$$c^s = \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{1}{(1-\alpha)}} \cdot \left(\frac{(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)}{\alpha} \right) \cdot T_0 \cdot e^{\omega t} \quad (85)$$

$$g_H^s = (x_H \bar{\tau}) \cdot \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (86)$$

$$g^s = taxr^s = \bar{\tau} \cdot \left(\frac{(1-\bar{\tau})\alpha}{(\rho+\theta\omega+(1-\bar{\tau})\delta)} \right)^{\frac{\alpha}{(1-\alpha)}} \cdot T_0 \cdot e^{\omega t} \quad (87)$$

The results show that in the absence of production externalities, the long-run values of k^s , y^s , c^s , and $g^s = taxr^s$ are the same for both models.⁸⁸ However, in this setting, the results show $(c_H^s)^1 > (c_H^s)^2$, $(c_O^s)^1 < (c_O^s)^2$, and of course, $(g_O^s (= g^s))^1 > (g_O^s)^2$. Finally, the long-run ratios of health expenditures implied by the two models can be compared as follows: Note that these long-run ratios are the same for all settings; that is, they do not change whether there is a production externality or not. Table 9 shows that at long-run equilibrium, (i) if the government is involved in the provision of health goods and services, the ratio of personal health consumption to total consumption decreases, but the ratio of consumption of other goods and services increases: $\left(\frac{c_H^s}{c^s}\right)^1 > \left(\frac{c_H^s}{c^s}\right)^2$ and $\left(\frac{c_O^s}{c^s}\right)^1 < \left(\frac{c_O^s}{c^s}\right)^2$, and (ii) similarly, $\left(\frac{c_H^s}{y^s}\right)^1 > \left(\frac{c_H^s}{y^s}\right)^2$ and $\left(\frac{c_O^s}{y^s}\right)^1 < \left(\frac{c_O^s}{y^s}\right)^2$. Finally, one can demonstrate that if $a \cdot (1 - \bar{\tau}) \cdot (1 - s^s) \cdot \left(\frac{(1-a)(1-\psi)}{1-a(1-\psi)}\right) > x_H \bar{\tau}$, then $\left(\frac{HEXP^s}{y^s}\right)^1 > \left(\frac{HEXP^s}{y^s}\right)^2$.

Table 9: Long-Run Ratios Implied by the Extended Ramsey Models (With and Without Production Externalities)

<i>Implied Ratios</i>	<i>1st Model (with personal health spending)</i>	<i>2nd Model (with personal and public health spending)</i>
$\frac{c_H^s}{c^s}$	a	$\left(\frac{a\psi}{1-a(1-\psi)}\right)$

⁸⁸ Of course, this is true only for the decentralized solutions of the models. For a social planner, the results of the second model will not be the same as those of the first model. Although it is straightforward to obtain centralized solutions for each setting, here the study disregards the solution of the social planner and focuses on the more realistic decentralized choices of an economy.

$\frac{c_0^s}{c^s}$	$(1 - a)$	$\left(\frac{1-a}{1-a(1-\psi)}\right)$
$\frac{c_H^s}{y^s}$	$\left(\frac{a(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)$	$\left(\frac{(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)\left(\frac{a\psi}{1-a(1-\psi)}\right)$
$\frac{c_0^s}{y^s}$	$(1 - a) \cdot \left(\frac{(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)$	$\left(\frac{(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)\left(\frac{1-a}{1-a(1-\psi)}\right)$
$\frac{g_H^s}{y^s}$	$n.a.$	$(x_H \bar{\tau})$
$\frac{HEXP^s}{y^s}$	$\left(\frac{a(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)$	$\left(\frac{(1-\bar{\tau})[(\rho+\theta\omega+(1-\bar{\tau})\delta)-\alpha(n+\omega+(1-\bar{\tau})\delta)]}{(\rho+\theta\omega+(1-\bar{\tau})\delta)}\right)\left(\frac{a\psi}{1-a(1-\psi)}\right) + (x_H \bar{\tau})$

Notes: $HEXP^s$ shows the long-run equilibrium value of total health expenditures available in the model economy. The findings are based on the market solutions of the models.

2.4. TWO EXTENDED SOLOW MODELS: THE EFFECTS OF HEALTH EXPENDITURES ON PRODUCTIVITY

This section produces two augmented Solow models in an attempt to examine the role of health expenditures in income convergence and long-run income growth. Although it is possible to perform a quantitative income convergence analysis using the above models⁸⁹, the convergence equations derived from using the Ramsey framework are not suitable for empirical research. Therefore, in this section, two augmented Solow models are presented (i) to empirically test the validity of an income convergence equation conditional on personal and public health expenditures in addition to other traditional determinants of Solow growth and (ii) to estimate the effects of health expenditures on long-run economic growth. In this context, for the sake of completeness and compatibility of the chapter, both models below were designed in parallel with the Ramsey models derived in the previous section. In other words, both augmented Solow models consider the effects of a production externality generated by personal and public health expenditures, but they are subject to an exogenous consumption-saving trade-off, unlike the augmented Ramsey models.

⁸⁹ Please refer to Barro and Sala-i Martin (2004: 111-113) for an analysis of the speed of convergence in a Ramsey framework.

2.4.1. Personal Health Expenditures in a Simple Model of Economic Growth

Assume that each consumer in a closed Solovian economy divides their consumption expenditures between health and other goods and services. It means that total consumer expenditures (C_t) include both personal health expenditures (C_{Ht}) and consumption expenditures on other goods and services (C_{Ot}), *i.e.*, $C_t = C_{Ht} + C_{Ot}$. On the other hand, personal consumption expenditures on health are still referred to as all expenditures that preserve and improve the good health status of the individual, including medical expenses and the cost of healthy food, among others. The model further assumes that there is a balanced-budget government in the economy that collects income taxes to offset its expenditures (G_t). The budget of the government can be represented as $G_t = \bar{\tau}Y_t = TAXR_t$, where $\bar{\tau}$ is the flat rate of income tax, $TAXR_t$ represents total tax revenue of the government, and $0 < \bar{\tau} < 1$.

Total expenditures in this economy are now defined as $Y_t \equiv C_{Ht} + C_{Ot} + I_t + G_t$, where I_t represents gross investments on physical capital $I_t = s_K \cdot Y_t$, s_K is the investment rate for physical capital (or the savings rate), and $0 < s_K < 1$. Given the definition of disposable income ($YD_t = (1 - \bar{\tau})Y_t$), in this model economy, total personal health consumption is assumed to be given by $C_{Ht} = mpc_H \cdot (1 - \bar{\tau})Y_t$, and hence, consumption expenditures on other goods and services are $C_{Ot} = mpc_O \cdot (1 - \bar{\tau})Y_t$. In other words, the model presumes that (i) total MPC out of disposable income (mpc) is defined as the sum of MPC for health goods and services (mpc_H) and MPC for other goods and services (mpc_O), *i.e.*, $mpc = mpc_H + mpc_O$ and (ii) $s_K \equiv 1 - mpc_H - mpc_O$.

Y_t equivalently represents total income or production output and is further equal to $Y_t = F(K_t, T_t, L_t, E_t) = Y_t = K_t^\alpha \cdot (T_t \cdot L_t \cdot E_t)^{1-\alpha}$, where K_t is the physical capital, L_t is total labor force, and T_t is overall technological progress. L_t and T_t are exogenously defined as $L_t = L_0 \cdot e^{nt}$ and $T_t = T_0 \cdot e^{\omega t}$.⁹⁰ The model, like the first Ramsey model presented in the previous section, continues to assume that personal

⁹⁰ Please note that all other details on the Solow setup as well as the definitions of the related parameters and variables are given both in Chapter 1 and in Appendix 1.

health expenditures generate a positive externality on the total workforce of the economy. Therefore, as before, $E_t = \check{c}_{Ht}^\gamma$ and $0 < \gamma < 1$. Based on the above assumptions, the production function of this Solovian economy in effective labor terms can be defined as $\check{y}_t = \check{k}_t^\alpha \cdot \check{c}_{Ht}^{\gamma(1-\alpha)}$, or equivalently,

$$\check{y}_t = \check{k}_t^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (mpc_H(1-\bar{\tau}))^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} \quad (88)$$

where $\check{y}_t$ is total output per effective labor $\check{y}_t = \frac{Y_t}{T_t \cdot L_t}$, $\check{k}_t$ is effective physical capital per labor $k_t = \frac{K_t}{T_t \cdot L_t}$, $\check{c}_{Ht}$ is personal health expenditures in effective labor terms $\check{c}_{Ht} = \frac{c_{Ht}}{T_t \cdot L_t} = mpc_H \cdot (1-\bar{\tau})\check{y}_t$, and the subindex t represents time. α and $1-\alpha$ represent the elasticities of total output with respect to physical capital and labor, respectively, and $0 < \alpha < 1$. Therefore, by using the augmented version of the production function in Eq. (88), the fundamental equation of growth in effective labor terms can be rewritten as follows:

$$\dot{\check{k}}_t = s_K \cdot (1-\bar{\tau}) \cdot \check{k}_t^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (mpc_H(1-\bar{\tau}))^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - (n + \omega + \delta) \cdot \check{k}_t \quad (89)$$

Eq. (89) gives the capital accumulation equation in effective labor terms, in which $\dot{\check{k}}_t$ is the change in the effective physical capital stock per labor and δ is the depreciation rate of the physical capital. As before, by assuming the existence of the steady state, one can easily show that $\dot{\check{k}}^s = 0$ if $\frac{d}{dt} \left(\frac{\dot{\check{k}}^s}{\check{k}^s} \right) = 0$ in Eq. (89). Hence, following the usual solution procedure (given in Appendix 1 in details), the long-run equilibrium values of the physical capital and output in effective labor terms can be obtained as follows:

$$\check{k}^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (mpc_H(1-\bar{\tau}))^{\frac{\gamma}{1-\gamma}} \quad (90)$$

$$\check{y}^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (mpc_H(1-\bar{\tau}))^{\frac{\gamma}{1-\gamma}} \quad (91)$$

Finally, if Eqs. (90)–(91) are transformed into per-worker terms, the long-run equilibrium values of all model variables can be found as follows:

$$k^s = (1 - \bar{\tau})^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot mpc_H^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (92)$$

$$y^s = (1 - \bar{\tau})^{\frac{\alpha+\gamma(1-\alpha)}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (mpc_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (93)$$

$$yd^s = (1 - \bar{\tau})^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (mpc_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (94)$$

$$c_H^s = (1 - \bar{\tau})^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot mpc_H^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (95)$$

$$c_O^s = mpc_O \cdot (1 - \bar{\tau})^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot mpc_H^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (96)$$

$$c^s = (1 - s_K) \cdot (1 - \bar{\tau})^{\frac{1}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot mpc_H^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (97)$$

$$g^s = \bar{\tau} \cdot (1 - \bar{\tau})^{\frac{\alpha+\gamma(1-\alpha)}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (mpc_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (98)$$

Eqs. (92)–(98) show that (i) all per-worker equilibrium values of the model variables grow at the constant rate of technological progress (ω) in the long run and (ii) the income tax rate negatively affects per worker steady-state values of the variables, except for per-worker expenditures of the government. That is, given the existence of a production externality, increases in the income tax rate would raise per-worker government expenditures if $\bar{\tau} < (1 - \alpha)(1 - \gamma)$. On the other hand, the share of personal health expenditures in total disposable income (mpc_H) positively affects the long-run equilibrium values of all model variables, depending on some parameter constraints as follows: (i) $\frac{\partial k^s}{\partial mpc_H} > 0$ if $\frac{s_K}{mpc_H} > \frac{1-\gamma+\alpha\gamma}{(1-\alpha)\gamma}$, (ii) $\frac{\partial y^s}{\partial mpc_H} > 0$, $\frac{\partial yd^s}{\partial mpc_H} > 0$, $\frac{\partial c^s}{\partial mpc_H} > 0$, and $\frac{\partial g^s}{\partial mpc_H} > 0$ if $\frac{s_K}{mpc_H} > \frac{\alpha}{(1-\alpha)\gamma}$, and (iii) $\frac{\partial c_O^s}{\partial mpc_H} < 0$ if $\frac{\gamma(1-\alpha)}{mpc_H} - \frac{\alpha}{s_K} < (1 - \alpha)(1 - \gamma)$. These parameter constraints that restrict the positive effects of mpc_H reflect (i) the exogenous trade-off between the savings rate and the share of personal health spending and (ii) the dual role of personal health spending in the model: it serves both as a positive externality on the labor force and as a component of total consumption expenditures.

Furthermore, one can show that $\frac{\partial c_H^s}{\partial mpc_H} > 0$ if $\frac{s_K}{mpc_H} > \frac{\alpha}{(1-\alpha)}$. That is, even the net impact of mpc_H on the steady-state value of personal health spending depends on the relative sizes of the two ratios: (i) the ratio of MPS over MPC for health and (ii) the ratio of the output share of physical capital over the output share of the total effective labor force. Lastly, the ratio of per-worker personal health expenditures to savings rate can be given by $\frac{c_H^s}{s_K^s} = \frac{mpc_H}{(1-mpc)(1-s_K)}$.

Based on the above findings, the role of personal health expenditures on income convergence can be derived as follows: First, Eq. (89) is re-expressed in terms of income per unit of effective labor ($\tilde{y}_t$) to obtain the following nonlinear differential equation:

$$\frac{\dot{\tilde{y}}_t}{\tilde{y}_t} = \frac{\alpha}{1-\gamma+\alpha\gamma} \left[s_K \cdot (1-\bar{\tau})^{\frac{\alpha(1-\gamma)+\gamma}{\alpha}} \cdot \tilde{y}_t^{\frac{(\alpha-1)(1-\gamma)}{\alpha}} \cdot mpc_H^{\frac{(1-\alpha)\gamma}{\alpha}} - (n + \omega + \delta) \right] \quad (99)$$

After log-linearization, Eq. (99) becomes

$$\frac{d \ln(\tilde{y}_t)}{dt} \approx - \left(\frac{(1-\alpha)(1-\gamma)}{1-\gamma+\alpha\gamma} \right) (n + \omega + \delta) [\ln(\tilde{y}_t) - \ln(\tilde{y}^s)] \quad (100)$$

and the speed of convergence (λ) can be defined as $\lambda = \left(\frac{(1-\alpha)(1-\gamma)}{1-\gamma+\alpha\gamma} \right) (n + \omega + \delta)$. Therefore, the solution of this linearized differential gives the following income convergence equation:⁹¹

$$\begin{aligned} \ln(y_{t_2}) - \ln(y_{t_1}) = & -(1 - e^{-\lambda\tau}) \ln(y_{t_1}) + (1 - e^{-\lambda\tau}) \left(\frac{\alpha}{(1-\alpha)(1-\gamma)} \right) \ln(s_K) - (1 - e^{-\lambda\tau}) \left(\frac{\alpha}{(1-\alpha)(1-\gamma)} \right) \ln(n + \omega + \delta) + \\ & (1 - e^{-\lambda\tau}) \left(\frac{\gamma}{1-\gamma} \right) \ln(mpc_H) + (1 - e^{-\lambda\tau}) \left(\frac{\gamma(1-\alpha)+\alpha}{(1-\alpha)(1-\gamma)} \right) \ln(1 - \bar{\tau}) + \\ & (1 - e^{-\lambda\tau}) \ln(T_0) + \omega(t_2 - e^{-\lambda\tau}t_1) \end{aligned} \quad (101)$$

⁹¹ Note that the solution procedure is provided in Appendix 1 in detail.

2.4.2. Public Health Expenditures in a Simple Model of Economic Growth

In this subsection, the above model is modified by adding two new assumptions. First, this model assumes that all health expenditures in an economy are provided by the government. In other words, total government expenditures (G_t) are now given by the sum of public expenditures on health (G_{Ht}) and on other goods and services (G_{Ot}). The model also assumes that each expenditure component of the government receives a constant share of total tax revenues, *i.e.*, $G_{Ht} = x_H \bar{\tau} Y_t$, $G_{Ot} = (1 - x_H) \bar{\tau} Y_t$, and $0 < x_H < 1$. Second, on the production side, the positive externality on labor is now generated by public health expenditures. That is, $E_t = \check{g}_{Ht}^\gamma$. Therefore, the intensive form of the production function and the fundamental equation of growth are now given by

$$\check{y}_t = \check{k}_t^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} \quad (102)$$

$$\dot{\check{k}}_t = s_K \cdot (1 - \bar{\tau}) \cdot \check{k}_t^{\frac{\alpha}{1-\gamma+\alpha\gamma}} \cdot (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - (n + \omega + \delta) \cdot \check{k}_t \quad (103)$$

and the long-run equilibrium values of the model variables in per-worker terms can be given as follows:

$$k^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (104)$$

$$y^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (105)$$

$$y d^s = (1 - \bar{\tau})^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (106)$$

$$c^s = (1 - s_K) \cdot (1 - \bar{\tau})^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{s_K}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (107)^{92}$$

⁹² It is worth noting that if $x_H = mpc_H$, then the difference in consumption per capita obtained from the two models is equal to $(1 - \bar{\tau})^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (\bar{\tau})^{\frac{\gamma}{1-\gamma}}$.

$$g^s = (\bar{\tau})^{\frac{1}{1-\gamma}} \cdot \left(\frac{S_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (108)$$

$$g_H^s = (\bar{\tau})^{\frac{1}{1-\gamma}} \cdot \left(\frac{S_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (109)$$

$$g_O^s = (1 - x_H) \cdot (\bar{\tau})^{\frac{1}{1-\gamma}} \cdot \left(\frac{S_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (110)$$

Eqs. (104)–(110) show that increases in the share of public health spending in total public expenditures (x_H) raise all per worker steady-state values of the model variables, *i.e.*, $\frac{\partial k^s}{\partial x_H} > 0$, $\frac{\partial y^s}{\partial x_H} > 0$, $\frac{\partial c^s}{\partial x_H} > 0$, $\frac{\partial yd^s}{\partial x_H} > 0$, $\frac{\partial g^s}{\partial x_H} > 0$, $\frac{\partial g_H^s}{\partial x_H} > 0$, and also $\frac{\partial g_O^s}{\partial x_H} > 0$ as long as $x_H < \frac{\gamma}{1-\gamma}$. The findings further indicate that $\frac{\partial k^s}{\partial \bar{\tau}} > 0$, $\frac{\partial yd^s}{\partial \bar{\tau}} > 0$, and $\frac{\partial c^s}{\partial \bar{\tau}} > 0$ if $\frac{1-\gamma+\alpha\gamma}{(1-\alpha)\gamma} < \left(\frac{1-\bar{\tau}}{\bar{\tau}} \right)$, and $\frac{\partial y^s}{\partial \bar{\tau}} > 0$ if $\frac{\alpha}{(1-\alpha)\gamma} < \left(\frac{1-\bar{\tau}}{\bar{\tau}} \right)$. However, $\frac{\partial g^s}{\partial \bar{\tau}} > 0$, $\frac{\partial g_H^s}{\partial \bar{\tau}} > 0$, and $\frac{\partial g_O^s}{\partial \bar{\tau}} > 0$ if $\frac{\alpha}{(1-\alpha)} < \left(\frac{1-\bar{\tau}}{\bar{\tau}} \right)$. Lastly, one can show that the income tax rates that optimize public health expenditures and output per worker are $\bar{\tau}^* = (1 - \alpha)$ and $\bar{\tau}^* = \frac{\gamma(1-\alpha)}{\alpha+\gamma(1-\alpha)}$, respectively.

To perform a convergence analysis, one can proceed as follows: Eq. (99) now implies that

$$\frac{\dot{\tilde{y}}_t}{\tilde{y}_t} = \frac{\alpha}{1-\gamma+\alpha\gamma} \left[S_K \cdot (1 - \bar{\tau}) \cdot \tilde{y}_t^{\frac{(\alpha-1)(1-\gamma)}{\alpha}} \cdot (x_H \bar{\tau})^{\frac{(1-\alpha)\gamma}{\alpha}} - (n + \omega + \delta) \right] \quad (111)$$

and after the Taylor approximation,

$$\frac{d \ln(\tilde{y}_t)}{dt} \approx - \left(\frac{(1-\alpha)(1-\gamma)}{1-\gamma+\alpha\gamma} \right) (n + \omega + \delta) [\ln(\tilde{y}_t) - \ln(\tilde{y}^s)] \quad (112)$$

where $\lambda = \left(\frac{(1-\alpha)(1-\gamma)}{1-\gamma+\alpha\gamma} \right) (n + \omega + \delta)$ is the rate of convergence. Thus, by following the standard convergence algebra, one can obtain the following income convergence equation, which is now conditional on the share of public health expenditures in total public expenditures in addition to other determinants of Solow growth.

$$\begin{aligned}
\ln(y_{t_2}) - \ln(y_{t_1}) = & -(1 - e^{-\lambda\tau})\ln(y_{t_1}) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{(1-\alpha)(1-\gamma)}\right)\ln(s_K) - (1 - e^{-\lambda\tau})\left(\frac{\alpha}{(1-\alpha)(1-\gamma)}\right)\ln(n + \omega + \delta) + \\
& (1 - e^{-\lambda\tau})\left(\frac{\gamma}{1-\gamma}\right)\ln(x_H) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{(1-\alpha)(1-\gamma)}\right)\ln(1 - \bar{\tau}) + \\
& (1 - e^{-\lambda\tau})\left(\frac{\gamma}{1-\gamma}\right)\ln(\bar{\tau}) + (1 - e^{-\lambda\tau})\ln(T_0) + \omega(t_2 - e^{-\lambda\tau}t_1)
\end{aligned} \tag{113}$$

2.5. EMPIRICAL RESEARCH

In the empirical part of this chapter, Eqs. (101) and (113) are estimated using the following panel data specifications:

Model A:

$$\begin{aligned}
\ln(y_{it}) - \ln(y_{i,t-1}) = & \gamma_1\ln(y_{i,t-1}) + \gamma_2\ln(s_{Kit}) + \gamma_3\ln(n_{it} + \omega + \delta_{it}) + \\
& \gamma_4\ln(mpc_{Hit}) + \gamma_5\ln(1 - \tau_{it}) + \theta\ln(X_{it}) + \varphi_i + \zeta_t + v_{it}
\end{aligned} \tag{114}$$

Model B:

$$\begin{aligned}
\ln(y_{it}) - \ln(y_{i,t-1}) = & \gamma_1\ln(y_{i,t-1}) + \gamma_2\ln(s_{Kit}) + \gamma_3\ln(n_{it} + \omega + \delta_{it}) + \\
& \gamma_4\ln(x_{Hit}) + \gamma_5\ln(1 - \tau_{it}) + \gamma_6\ln(\tau_{it}) + \theta\ln(X_{it}) + \varphi_i + \zeta_t + v_{it}
\end{aligned} \tag{115}$$

Eqs. (101) and (102) measure the contribution of health expenditures provided by households and the public to income growth and convergence, respectively. In this context, Model A (Eq. 114) shows the effects of personal health spending, while Model B (Eq. 115) indicates the role of public health spending in income growth and the convergence process. In each model, the dependent variable is the log difference of real per capita income over some τ -year period. $\gamma_1 = -(1 - e^{-\lambda\tau})$ is the coefficient of the log of real per capita income in the previous τ -year span and theoretically expected to be negative to be consistent with the convergence idea. In this sense, a lower γ_1 (a higher γ_1 in absolute value) indicates the presence of faster convergence. $\gamma_2 = (1 - e^{-\lambda\tau})\left(\frac{\alpha}{(1-\alpha)(1-\gamma)}\right)$ is the coefficient of the savings rate. $\gamma_3 = -(1 - e^{-\lambda\tau})\left(\frac{\alpha}{(1-\alpha)(1-\gamma)}\right)$ shows the effects of the augmented rate of population growth on

income growth. The coefficient γ_4 measures the contribution of health expenditures to per capita income growth. In this sense, in Model A, $\gamma_4 = (1 - e^{-\lambda\tau}) \left(\frac{\gamma}{1-\gamma} \right)$ shows the growth effects of the share of personal health expenditures in disposable income ($mpc_{H_{it}}$), whereas it shows the effects of the share of public health expenditures in total government expenditures ($x_{H_{it}}$) if Model B is considered.

On the other hand, in each model, the coefficient γ_5 shows the effects of the shortfall of the income tax rate from one ($1 - \bar{\tau}$). However, theoretically, $\gamma_5 = (1 - e^{-\lambda\tau}) \left(\frac{\gamma(1-\alpha)+\alpha}{(1-\alpha)(1-\gamma)} \right)$ in Model A and $\gamma_5 = (1 - e^{-\lambda\tau}) \left(\frac{\alpha}{(1-\alpha)(1-\gamma)} \right)$ in Model B. Model B further includes the coefficient $\gamma_6 = (1 - e^{-\lambda\tau}) \left(\frac{\gamma}{1-\gamma} \right)$, which measures the effect of the income tax rate ($\bar{\tau}$) on income growth. Additionally, in each equation, θ represents the coefficients of the control variables and X_{it} is the vector of control variables, which includes human capital in the form of education and trade openness to partly eliminate omitted variable bias in the estimations. $\varphi_i = (1 - e^{-\lambda\tau}) \ln(T_0)$ measures country-specific omitted factors and $\zeta_t = \omega(t_2 - e^{-\lambda\tau}t_1)$ gives the impact of common macroeconomic shocks on income growth in all sample countries. In other words, empirical estimations assume identical but not constant technological progress across sample countries. Lastly, v_{it} is the usual error component of the regression, i indicates cross-sectional units, and t denotes time points.

2.5.1. Empirical Methodology

Similar to Chapter 1, Eqs. (114) and (115) are estimated by using the system GMM estimator, given the shortcomings of other approaches faced by traditional convergence research.⁹³ Briefly, by including both individual and period fixed effects in the regression equation, the system GMM estimator considers the differences both in the initial level of productivity and the temporal differences in technological change that are common across all sample countries. Furthermore, the estimator (i) allows the inclusion of more instruments, (ii) reduces finite sample bias, and (iii) improves the

⁹³ A comprehensive explanation of the system GMM approach and PURTs is provided in Section 1.4.1 of Chapter 1.

precision for short panels. On the other hand, this estimator deals with any endogeneity problem that exists between income and other determinants of growth.

In this sense, several studies have found that there is a bidirectional causality between health expenditures and real income (Amiri and Ventelou, 2012; Devlin and Hansen, 2001; Erdil and Yetkiner, 2009; Kumar, 2013; Rivera and Currais, 1999a, 1999b, 2003; Wang, 2011), while others have noticed that there is a unidirectional causality from health expenditures to real income (Heshmati, 2001). Therefore, the existence of this strong and robust feedback relationship between health expenditures and real income—in addition to those of the investment rate and taxes—is one of the main reasons for using the system GMM estimator in the following estimations. Finally, before system GMM estimations, the time-series properties of the sample variables are also examined in the study to avoid any unreliable results.

2.5.2. Data

This chapter uses an unbalanced panel dataset for two different groups of countries, OECD members and LDCs, which are quite different in terms of the health care models they have adopted. For instance, all OECD members except for the U.S. have a universal health care system with different funding models. That is, in these countries, the majority of individuals have some access to basic health care services without financial hardship. Additionally, the health care systems in these countries are mostly financed through a mix of public and private contributions, and tax revenue is the main source of funding. On the other hand, most of the LDCs have a non-universal health care system, in which the vast majority of the population does not have full access to essential health care services. Although some of the LDCs, including Benin, Comoros, Liberia, and Timor-Leste, have joined the Universal Health Coverage (UHC) partnership in recent years, they are still far from reaching a comprehensive health care system due to their limited resources.⁹⁴ Furthermore, the health care systems in LDCs generally rely on some private contributions and mostly on the out-of-pocket health expenditures of the individuals. Therefore, this study includes both

⁹⁴ For more information, please visit <https://www.uhcpartnership.net/>

groups of countries in the empirical analyses to compare and examine the effects of these differences on the relationship between income growth and health expenditures.

The sample set of the study covers a total of 38 OECD members and 34 LDCs.⁹⁵ The choice of LDCs is based on the country classification of the UN. In this context, the UN classifies 46 countries as LDCs in the international era due to their lower socio-economic development levels.⁹⁶ However, due to a lack of data, only 34 countries are included in the analyses. These 34 LDCs further include a mix of low- and lower-middle-income countries of the WB. On the other hand, OECD countries include high- and upper-middle-income countries of the WB and mostly refer to developed countries of the UN. According to the UN, only Chile, Colombia, Costa Rica, Israel, the Republic of Korea, Mexico, and Turkey are among the developing economies.

Regarding the Solow growth variables, the study uses real per capita income (y_{it}), which is obtained by dividing real GDP (in millions of 2017 US dollars) by the total population (in millions) of a country. In line with theoretical models, using per capita variables is more appropriate for this study to be able to focus on the effects of health expenditures provided for the entire population and not for a particular group, in contrast to Chapter 1. The savings rate (s_{Kit}) is proxied by the share of gross capital formation at current PPPs. The annual growth rate of the total population (n_{it}) is calculated from the data on the total population (in millions), and the depreciation rate (δ_{it}) is measured by the average depreciation rate of the capital stock. Hence, the effective depreciation rate ($n_{it} + \omega + \delta_{it}$) is obtained as the sum of the population growth rate, the depreciation rate of the physical capital, and the constant rate of technological progress (ω), which is equal to 2% as in Mankiw *et al.* (1992). All the data on Solow growth variables were obtained from the PWT (Feenstra *et al.*, 2015).⁹⁷

The study uses two groups of proxy variables for health expenditures. To proxy for personal health expenditures (*i.e.*, mpc_H in the first theoretical model), the study employs (i) the percentage share of per capita private health expenditures (US\$) in real per capita income (mpc_{Hit}), (ii) the percentage share of private health expenditures

⁹⁵ The list of countries is provided in Appendix 4 in Table 1.

⁹⁶ The list of all 46 LDCs can be found in the Statistical Annex of the UN (2022) report on World Economic Situation and Prospects.

⁹⁷ PWT version 10.0 was used in the study, which was revised in June 2021.

in total health expenditures ($PRIVATE_{it}$), and (iii) the percentage share of out-of-pocket health expenditures in total health expenditures ($POCKET_{it}$). In this sense, private sources include funds from households, corporations, and non-profit organizations, while out-of-pocket health expenditures are directly provided from the pockets of households. Although mpc_H is theoretically defined as the ratio of total personal health expenditures to disposable income, due to data availability, the analyses include the three proxies mentioned above to refer to health expenditures provided outside of the public sector and to estimate the impact on growth of as many different sources of health expenditures as possible. Moreover, to proxy for x_H , which is theoretically defined as the ratio of government health expenditures over total public spending, the study uses the percentage share of government health expenditures in (i) total government expenditures ($x_{H_{it}}$), (ii) total GDP ($PUBLIC/GDP_{it}$), and (iii) total health expenditures ($PUBLIC_{it}$). Lastly, the study includes the percentage share of external health expenditures in total health expenditures ($EXTERNAL_{it}$), which are funded from external sources, including direct foreign transfers through governments and non-governmental organizations. All data on health expenditures came from the WDI of the WB (2022).

Furthermore, the percentage share of taxes on income, profits, and capital gains in total taxes was obtained from the WDI of the WB to proxy for the income tax rate (τ_{it}) given in Eq. (115). The shortage of the income tax rate from one ($(1 - \tau_{it})$) was also calculated using the same data as in the estimations of Eqs. (114) and (115). The study also includes two control variables, including human capital in the form of education (HC_{it}) and trade openness ($OPEN_{it}$), to partly eliminate omitted variable bias in the analyses. The data on human capital is measured as an index that includes schooling years and returns to education, and trade openness is calculated as the percentage sum of the shares of merchandise exports and imports at current PPPs. Both series were drawn from the PWT (Feenstra *et al.*, 2015). Once and for all, the study opts for non-overlapping time intervals widely used in the empirical convergence literature to minimize business cycle effects that dominate the short-run variations in growth rates. Hence, the data were averaged by using non-overlapping 3-year time intervals to obtain as many time points as possible, given the time dimension of the sample panel used in the study. The two final sample sets include a total of seven time

points observed over 3-year intervals over the years between 2000 and 2019. All explanatory variables are used in their natural log forms in the analyses.

Table 10: Descriptive Statistics

	<i>Mean</i>	<i>Median</i>	<i>Std. Dev.</i>	<i>Min.</i>	<i>Max.</i>
PANEL A <i>38 OECD Members: 2000-2019</i>					
y_{it} (2017, US\$)	38014.16	37753.71	16856.88	8577.56	96812.32
$s_{K_{it}}$ (%)	23.66	22.53	11.54	-47.85	165.03
n_{it} (%)	0.58	0.55	0.76	-1.55	2.54
δ_{it} (%)	4.30	4.23	1.31	0.00	10.00
$mpc_{H_{it}}$ (%)	1.97	1.67	1.45	0.17	9.03
$PRIVATE_{it}$ (%)	29.69	27.64	12.18	11.30	71.43
$POCKET_{it}$ (%)	21.03	18.74	9.19	7.14	55.66
$x_{H_{it}} = \frac{G_H}{G_t}$ (%)	14.22	13.74	3.95	7.19	33.10
$(PUBLIC/GDP)_{it}$ (%)	5.78	5.85	1.69	1.96	9.28
$PUBLIC_{it}$ (%)	70.21	72.35	12.19	28.57	88.70
$EXTERNAL_{it}$ (%)	0.15	0.00	0.41	0.00	2.33
$(1 - \tau_{it})$ (%)	56.25	57.36	15.50	7.41	90.46
τ_{it} (%)	43.75	42.64	15.50	9.54	92.59
HC_{it} (index)	2.51	2.60	0.69	1.11	3.77
$OPEN_{it}$ (%)	-9.85	-5.81	63.81	-1493.40	631.96
PANEL B <i>34 LDCs: 2000-2019</i>					
y_{it} (2017, US\$)	2457.57	1894.77	1755.60	622.32	11692.74
$s_{K_{it}}$ (%)	23.74	22.09	32.44	-130.69	812.28
n_{it} (%)	2.44	2.70	0.91	-0.61	5.77
δ_{it} (%)	4.34	4.25	1.36	0.00	9.82
$mpc_{H_{it}}$ (%)	0.86	0.71	0.53	0.08	3.44
$PRIVATE_{it}$ (%)	50.01	51.39	18.75	8.35	87.94
$POCKET_{it}$ (%)	44.79	45.01	19.13	5.55	85.90
$x_{H_{it}} = \frac{G_H}{G_t}$ (%)	6.29	5.81	2.87	1.29	18.29
$(PUBLIC/GDP)_{it}$ (%)	1.30	1.11	0.86	0.06	5.56
$PUBLIC_{it}$ (%)	27.19	24.16	14.94	3.93	79.67
$EXTERNAL_{it}$ (%)	22.89	19.80	15.96	0.00	75.33
$(1 - \tau_{it})$ (%)	66.95	71.26	16.47	10.60	92.90
τ_{it} (%)	33.05	28.74	16.47	7.10	89.40
HC_{it} (index)	2.46	2.52	0.70	1.08	4.35
$OPEN_{it}$ (%)	-8.66	-5.77	115.94	-2211.67	1878.14

Note: Std. Dev., Min., and Max. refer to the standard deviation, the minimum, and the maximum, respectively.

Panels A and B of Table 10 show the descriptive statistics of the annual data for the two country groups over the years between 2000 and 2019. Table 10 clearly demonstrates the differences among both country groups in terms of the funding sources for their health expenditures. In this sense, the average shares of health expenditures from public sources are higher in OECD countries compared to LDCs, while this is not true if health expenditures provided from other sources are considered. In other words, over the sample period, the average share of public health expenditures

in total health expenditures was about 70.21% in the 38 OECD members, while this share was only about 27.19% in LDCs. On the other hand, in terms of private health expenditures, the average share was about 50.01% in LDCs, while this share was about 29.69% in OECD countries. Similarly, over the sample period, the average share of out-of-pocket expenditures in total health expenditures was higher in LDCs, with a rate of about 44.79%, reflecting that a significant burden of health care financing bears on the households in these countries. However, this share was only about 21.03% in the OECD group.

Lastly, health expenditures in most of the OECD countries were not funded by external sources over a 20-year period, except for Chile, Colombia, Costa Rica, Estonia, Greece, Israel, Latvia, Lithuania, Luxembourg, Poland, Portugal, and the United Kingdom. The average share of external health expenditures in total health expenditures was about 0.15% for these countries over the years 2000-2019. However, for LDCs, the average share of external sources used to fund their health care systems was about 22.89% over the same sample period. Furthermore, Table 10 clearly reflects the differences in the demographic stages of the two country groups. That is, the average population growth rate was less than 1% in high-income OECD countries, while LDCs countries continued to experience a high level of positive population growth with a rate of about 2.44% over the sample period. Two more remarkable observations from Table 10 are that (i) there were no significant differences between the two country groups in terms of both the average savings rate and the average human capital index, but (ii) in terms of the savings rates, there was a significant deviation among LDCs compared to OECD members.

2.5.3. Empirical Findings

Three first-generation unit root tests proposed by LLC (2002), IPS (2003), and Choi (2001), as well as a second-generation test suggested by Pesaran (2007), were applied to identify the stationarity properties of the annual series used in the analyses.⁹⁸ In this context, Tables 11 and 12 report the results of PURTs for the natural logarithms of the annual series in OECD and LDC samples, respectively. In each table, Panel A

⁹⁸ The HT (1999) test requires strongly balanced data.

shows the test results for the log-levels of the sample series, while Panel B provides the results for the first differences in logs. The results in Tables 11 and 12 show that the sample series does not suffer from unit root issues.

Table 11: Results of PURTs for the OECD

	<i>LLC</i> <i>Adjusted t*</i>	<i>IPS</i> <i>W-t-stat.</i>	<i>CHOI ADF</i> <i>Z-stat.</i>	<i>PESARAN</i> <i>CIPS</i>
PANEL A	LOG LEVELS			
$\ln(y_{it}) - \ln(y_{i,t-1})$	-12.459***	-7.581***	-7.515***	-2.895***
$\ln(y_{i,t-1})$	-2.428***	-2.950***	-2.966***	-3.951***
$\ln(s_{Kit})$	-18.477***	-17.716***	-14.774***	-3.208***
$\ln(n_{it} + \omega + \delta_{it})$	-14.551***	-12.594***	-11.454***	-3.320***
$\ln(mpc_{Hit})$	-3.433***	3.549	4.135	-2.622*
$\ln(PRIVATE_{it})$	-2.324***	-1.643**	-1.253*	-0.999
$\ln(POCKET_{it})$	-2.613***	-1.846**	-1.553*	-1.286
$\ln(x_{Hit})$	-7.260***	-7.065***	-6.227***	-4.156***
$\ln(PUBLIC_{it}/GDP_{it})$	-1.720**	-2.096**	-1.784**	-1.577
$\ln(PUBLIC_{it})$	-2.566***	-1.770**	-1.378*	-1.664
$\ln(EXTERNAL_{it})$	-132.108***	-19.288***	-2.204**	---
$\ln(1 - \tau_{it})$	-89.029***	-5.342***	-5.282***	---
$\ln(\tau_{it})$	-2.324***	-5.283***	-5.121***	---
$\ln(HC_{it})$	-8.837***	-2.537***	-4.323***	---
$\ln(OPEN_{it})$	-15.734***	-13.631***	-11.852***	-3.136***
PANEL B	FIRST DIFFERENCES IN LOGS			
$\ln(y_{it}) - \ln(y_{i,t-1})$	-20.359***	-17.073***	-14.753***	-3.029***
$\ln(y_{i,t-1})$	-10.969***	-6.285***	-6.433***	-2.610*
$\ln(s_{Kit})$	-17.719***	-21.766***	-16.339***	-5.353***
$\ln(n_{it} + \omega + \delta_{it})$	-11.610***	-17.803***	-14.862***	-5.734***
$\ln(mpc_{Hit})$	-15.820***	-13.085***	-11.953***	-3.430***
$\ln(PRIVATE_{it})$	-15.682***	-13.321***	-11.631***	-3.396***
$\ln(POCKET_{it})$	-12.429***	-11.556***	-10.416***	-2.811**
$\ln(x_{Hit})$	-15.141***	-14.580***	-12.328***	-3.756***
$\ln(PUBLIC_{it}/GDP_{it})$	-15.300***	-12.354***	-11.434***	-2.734**
$\ln(PUBLIC_{it})$	-15.806***	-12.937***	-11.268***	-3.435***
$\ln(EXTERNAL_{it})$	-65.412***	-22.378***	-6.486***	---
$\ln(1 - \tau_{it})$	-11.683***	-12.085***	-10.741***	---
$\ln(\tau_{it})$	-13.420***	-12.813***	-11.023***	---
$\ln(HC_{it})$	-17.177***	-4.534***	-8.100***	---
$\ln(OPEN_{it})$	-16.028***	-20.237***	-16.109***	-4.047***

Notes: For each test, the null hypothesis tests the existence of unit root. An intercept and a linear time trend are included in each test for each series. AIC is used to determine the optimal lag lengths. ***, **, and * refer to significance levels of 1%, 5%, and 10%, respectively. --- means that CIPS statistics cannot be calculated because of highly unbalanced series.

Table 12: Results of PURTs for LDCs

	<i>LLC</i> <i>Adjusted t*</i>	<i>IPS</i> <i>W-t-stat.</i>	<i>CHOI ADF</i> <i>Z-stat.</i>	<i>PESARAN</i> <i>CIPS</i>
PANEL A				
LOG LEVELS				
$\ln(y_{it}) - \ln(y_{i,t-1})$	-10.867***	-10.948***	-9.455***	-5.854***
$\ln(y_{i,t-1})$	-2.624***	1.582	1.912	-2.815**
$\ln(s_{Kit})$	-13.938***	-12.873***	-11.486***	-3.452***
$\ln(n_{it} + \omega + \delta_{it})$	-14.585***	-12.487***	-10.906***	-4.009***
$\ln(mpc_{Hit})$	-3.241***	-0.378	0.060	-3.726***
$\ln(PRIVATE_{it})$	-3.832***	-2.906***	-2.795***	-2.184
$\ln(POCKET_{it})$	-2.670***	-1.928**	-1.770**	-2.720**
$\ln(x_{Hit})$	-3.451***	-3.169***	-2.681***	-2.614*
$\ln(PUBLIC_{it}/GDP_{it})$	-11.090***	-5.420***	-2.622***	-2.630*
$\ln(PUBLIC_{it})$	-3.063***	-2.019**	-1.872**	-3.382***
$\ln(EXTERNAL_{it})$	-10.959***	-6.045***	-4.734***	-3.027***
$\ln(1 - \tau_{it})$	-2.841***	-0.816	-1.791**	---
$\ln(\tau_{it})$	-3.473***	-0.730	-1.643**	---
$\ln(HC_{it})$	-9.943***	-3.420***	-5.253***	---
$\ln(OPEN_{it})$	-14.032***	-13.010***	-11.409***	-2.616*
PANEL B				
FIRST DIFFERENCES IN LOGS				
$\ln(y_{it}) - \ln(y_{i,t-1})$	-18.453***	-19.226***	-14.571***	-3.236***
$\ln(y_{i,t-1})$	-9.855***	-9.646***	-8.599***	-3.298***
$\ln(s_{Kit})$	-13.643***	-18.555***	-14.829***	-10.997***
$\ln(n_{it} + \omega + \delta_{it})$	-17.404***	-22.899***	-17.283***	-5.253***
$\ln(mpc_{Hit})$	-13.069***	-12.288***	-11.005***	-2.666*
$\ln(PRIVATE_{it})$	-14.561***	-13.712***	-12.318***	-2.917*
$\ln(POCKET_{it})$	-15.934***	-13.707***	-12.222***	-2.795**
$\ln(x_{Hit})$	-22.037***	-18.406***	-13.695***	-4.557***
$\ln(PUBLIC_{it}/GDP_{it})$	-20.167***	-16.652***	-12.963***	-2.791**
$\ln(PUBLIC_{it})$	-16.743***	-15.926***	-13.639***	-3.577***
$\ln(EXTERNAL_{it})$	-18.320***	-16.885***	-14.168***	-3.176***
$\ln(1 - \tau_{it})$	-11.562***	-4.832***	-6.926***	---
$\ln(\tau_{it})$	-13.130***	-5.748***	-8.105***	---
$\ln(HC_{it})$	-17.926***	-4.345***	-7.656***	---
$\ln(OPEN_{it})$	-14.482***	-19.156***	-14.991***	-9.052***

Notes: For each test, the null hypothesis tests the existence of unit root. An intercept and a linear time trend are included in each test for each series. AIC is used to determine the optimal lag lengths. ***, **, and * refer to significance levels of 1%, 5%, and 10%, respectively. --- means that CIPS statistics cannot be calculated because of highly unbalanced series.

Tables 13–17 report the results of system GMM estimations. In all regressions, the LHS variable is the change in the logarithm of real per capita income. The lagged log-level of real per capita income is treated as predetermined in each regression, and all independent variables are considered endogenous, *i.e.*, they are assumed to be correlated with the shocks to real per capita income both in the current and in the

previous 3-year periods. The augmented rate of population growth is treated as potentially endogenous following Cho (1996) and Bond *et al.* (2001). Time dummies are also included in all regressions to prevent any possible evidence of simultaneous correlation (Roodman, 2009a). Each model is estimated by using a one-step GMM estimator since (i) the efficiency gains from using a two-step estimator are very small for the system GMM, (ii) the one-step estimator is always more reliable for finite sample inference even in the cases of non-normality and heteroskedasticity (Blundell and Bond, 1998: 142), and (iii) the asymptotic *t*-ratios are more precise for the one-step estimator due to the independence of its weight matrix compared to its two-step counterpart (Blundell and Bond, 2000; Bond, 2002; Bond and Windmeijer, 2002).

The bottom part of each of Tables 13–17 provides the test statistics used to verify the consistency of the system GMM estimator. In this sense, the estimator requires that (i) the instruments and the error term must be uncorrelated and (ii) the subsets of the instruments (or extra moment restrictions imposed by Blundell and Bond (1998)) must be valid. These two conditions are tested by means of Hansen's (1982) *J*- and *C*-statistics, respectively. The test results show that the instruments and their subsets are valid in all estimations. Third, the existence of autocorrelation should be checked by means of the *z*-test proposed by Arellano and Bond (1991). The *p*-values of the *z*-test statistics for first- (*AR*(1)) and second-order autocorrelation (*AR*(2)) are provided at the bottom of Tables 13–17. The results in all columns show that there is no second-order serial correlation. Finally, the system GMM approach requires that the number of groups be greater than or equal to the number of instruments used in the regressions (Roodman, 2009a). This requirement is also met in each estimation.

Tables 13–15 provide the estimation results for OECD countries. In this sense, Table 13 gives the findings from the estimations of Models A and B but without including the tax and control variables. In Table 13, column (1) provides the estimation results for absolute convergence, and column (2) gives the results on conditional convergence that do not consider the effects of health expenditures, *i.e.*, the basic Solow model. In line with the findings of the convergence literature, the findings in columns (1) and (2) provide support for absolute and faster conditional income convergence among structurally similar high-income countries (Barro, 1991; Barro and Sala-i-Martin, 1990; Islam, 1995; Mankiw *et al.*, 1992). According to the results

in column (2), the coefficient on the lagged log-level of real per capita income is significantly negative, indicating that 38 OECD members converge conditionally with an implied rate of convergence (λ) of around 4.9% per annum.⁹⁹ This finding indicates that 38 OECD members reach the halfway point of the steady state in about 14 years. Moreover, the results in column (2) show that the estimated effect of the savings rate is significantly positive, while the effect of the augmented rate of population growth is positive but insignificant.

Columns (3)–(5) of Table 13 give the findings from the estimation of Model A, in which the effects of personal and private health expenditures are considered. According to the results, the lagged log-level of real per capita income is highly significant and negative in each column, indicating the existence of conditional income convergence among OECD members. The coefficient of the savings rate is still positive and highly significant in each column, showing that a 1% percentage increase in the savings rate leads to about a 0.27% increase in the growth rate of real per capita income. However, the coefficient of the population growth rate is insignificant in each column. With regard to health expenditures, the findings significantly show that the shares of private health expenditures in both total income and total health expenditures have a significantly positive effect on the growth rate of per capita real income. That is, each one-percentage increase in the share of per capita private health expenditures in total per capita income ($mpc_{H_{it}}$) raises the income growth rate by about 0.06%, while each one-percentage increase in the share of private health expenditures in total health expenditures ($PRIVATE_{it}$) raises income growth by about 0.09%. However, out-of-pocket payments ($POCKET_{it}$) by households have no significant effect on income growth among OECD countries.¹⁰⁰ Furthermore, the highest convergence rate is obtained in column (3), in which the share of per capita private health expenditures in total per capita income ($mpc_{H_{it}}$) is included in the regressions.

Columns (6)–(8) of Table 13 show the findings from the estimation of Model B, in which the proxies for public health expenditures are included in the analyses. The

⁹⁹ In each Table, the calculations for implied convergence rates presume $\tau = 3$.

¹⁰⁰ The share of external health expenditures in total health expenditures ($EXTERNAL_{it}$) cannot be included in the regressions of OECD countries, as this share is exactly equal to zero for most of the members.

findings show that only the share of public health expenditures in total income ($PUBLIC_{it}/GDP_{it}$) is significant in column (7). In this sense, the results show that increasing the share of public health expenditures in total income by one percentage point lowers the growth rate of per capita income by about 0.12%. This finding is similar to the findings of Jones (1990) and Weber and Singh (1997), who found that public health expenditures negatively affect the long-run growth rate of high-income countries. The results in column (7) further show that if the regression is controlled for the effects of public health expenditures, the positive growth effect of the savings rate significantly decreases compared to other columns. On the other hand, the share of public health expenditures both in total public spending ($x_{H_{it}}$) and in total health expenditures ($PUBLIC_{it}$) has no significant effect on economic growth. In terms of convergence dynamics, the findings in columns (6)–(8) show that there is evidence of conditional income convergence among OECD countries. However, the findings further show that increases in the share of public health spending in total income significantly decrease the implied convergence rate among the 38 members. In other words, increases in public health spending decrease the estimated rate of convergence to about 3.06% per annum, which is even lower than the estimated rate of absolute convergence found in column (1).

Tables 14 and 15 provide the results from the estimations of Models A and B if the tax and control variables are included in the regressions.¹⁰¹ Columns (1)–(3) of each table present the results that take into account the effects of personal and private health expenditures, while columns (4)–(6) show the findings with respect to public health expenditures. According to the results, after controlling income taxation, all variables of health expenditures become insignificant in each column of Table 14, except for column (5). The results in column (5) show that the share of public health expenditures in total income ($PUBLIC_{it}/GDP_{it}$) is positively significant, implying that a 1% increase in the share of public health expenditures raises the growth rate of income by about 0.22%. The results also show that in this case, the implied convergence rate rises to around 6.5% per year when compared to the estimates in column (7) of Table 13. On the other hand, in Table 15, no significant results were

¹⁰¹ In each table, the number of groups decreases to 37 as Japan is excluded from the sample due to a lack of data on income tax.

obtained from the estimations of Models A and B when the regressions further included the control variables. Nevertheless, the findings in each of tables 14–15 commonly show that (i) there is strong evidence of conditional income convergence among OECD members, (ii) the savings rate has a positive and highly significant effect on income growth and the convergence process, and (iii) the population growth rate has no significant effect on long-run income growth among OECD members.

Tables 16–17 provide the estimation results for LDCs. Table 16 gives the findings from the estimations of Models A and B without including the tax variables, and Table 17 provides the results for the complete models that include the effects of government taxation.¹⁰² As before, columns (1) and (2) of Table 16 show the estimation results for absolute and conditional convergence, respectively. In contrast to the results of OECD members, the findings in columns (1) and (2) show evidence of absolute and faster income divergence among 34 LDCs. According to the results in column (2), 34 LDCs diverge conditionally with an implied rate of around 5.7% per annum. This finding clearly originates from the fact that these 34 LDCs cover both low- and lower-middle-income countries of the WB and still cannot catch up with each other due to serious differences that exist between their per capita income levels. Furthermore, the results in column (2) show that the estimated effect of the savings rate on growth is significantly positive for LDCs, while the effect of the population growth rate is positive but insignificant. Columns (3)–(5) of Table 16 present the findings from the estimation of Model A, while columns (6)–(8) show the findings from Model B.

For each case, the findings show that only the share of per capita private health expenditures in total per capita income ($mpc_{H_{it}}$) has a significant effect on the growth rate of real per capita income, while all coefficients on other proxies for health expenditures are found to be insignificant. The results in column (3) further show that, in contrast to the findings for OECD members, increases in the share of per capita private health expenditures significantly decrease the income growth rate among

¹⁰² In Table 17, the number of groups is equal to 21 since 13 countries (Benin, Burundi, Djibouti, Congo, Comoros, Chad, Gambia, Guinea, Haiti, Lao PDR, Mauritania, Niger, and Sierra Leone) are excluded from the sample due to a lack of data on taxation. Therefore, for the sample of LDCs, I could not include any control variables in the estimations as the number of instruments exceeded the number of groups in each case due to the low number of countries.

LDCs. That is, a 1% increase in the share of per capita private health expenditures decreases income growth by about 0.11% among 34 LDCs. Additionally, the results in column (9) of Table 16 show that the coefficient on the share of external health expenditures ($EXTERNAL_{it}$) is significantly negative for LDCs, indicating that each percentage increase in the share of external health expenditures surprisingly lowers per capita income growth by about 0.08%. Furthermore, the findings in columns (3)–(9) indicate that in each case: (i) there is no evidence of convergence or divergence among LDCs as the lagged log-level of real per capita income is insignificant, (ii) the savings rate has a positive and highly significant effect on income growth, and (iii) the population growth rate is not related to the income growth of 34 LDCs.

Finally, Table 17 provides the results for Models A and B by including the tax variables in the analyses. Columns (1)–(3) give the findings from the estimations of Model A, in which the effects of personal and private health expenditures are considered. The findings indicate that the lagged log-level of real per capita income is highly significant and negative in each column (1)–(3), indicating the existence of conditional income convergence among LDCs. However, regarding the coefficients of health expenditure proxies, the findings show that only the share of out-of-pocket health expenditures ($POCKET_{it}$) has a positive and significant effect on income growth and the convergence process. In this sense, the findings in column (3) indicate that a one percentage point increase in the share of out-of-pocket health expenditures raises the income growth rate by about 0.08%. Furthermore, the findings significantly show that increasing the out-of-pocket expenditures of households, which are the primary source of health care financing in most LDCs, allow this group of countries to close their income gaps at an estimated rate of about 4.7% per annum. In other words, the findings technically show that these countries can reach the halfway point of the steady state in about 15 years by increasing the out-of-pocket expenditures of the individuals. Hence, this finding may further imply that it seems impossible for these countries to converge even with each other as long as they maintain their current practices.

On the other hand, the findings in columns (1)–(3) of Table 17 further show that (i) in contrast to OECD members, the share of private health expenditures both in total income and in total health expenditures has no significant impact on the income

growth of LDCs, (ii) there is evidence of convergence among LDCs if one controls for the level of income taxation in the regressions, (iii) the savings rate has a positive and significant effect on income growth in each case, and (iv) the population growth rate has a negative and even significant effect on the growth rate of LDCs. Lastly, columns (4)–(6) of Table 17 show the findings from the estimations of Model B, in which the proxies for public health expenditures are included in the analyses. The findings show that the coefficients of all variables on public health expenditures are significant in each column. In this sense, the results show that, in each case, increasing the share of public health expenditures significantly decreases the growth rate of per capita income. The results further show that there is no evidence of convergence among LDCs. All other explanatory variables are insignificant in each column (4)–(6), except for the savings rate. As before, the savings rate has a significant and positive effect on the per capita income growth of LCDs.

To sum up, regarding the effects of health expenditures, the empirical results of the study show that the share of private health expenditures both in total per capita income and in total health expenditures has a positive and significant impact on long-run income growth and the convergence process among OECD countries. However, for this country group, the effects of public health expenditures on growth are significant, but the direction of these effects is ambiguous. Furthermore, the results of the study indicate that the growth effects of public health expenditures are larger in magnitude (if they are significant) than those of private ones in OECD countries. A rough comparison can be made between the findings of this study and previous studies, although it is not possible to make a direct comparison due to the differences in methodology and the samples used. In this sense, the findings of this study are in line with the results of Beraldo *et al.* (2005), who found that private health expenditures significantly and positively relate to growth in OECD countries and that the growth effects of public health expenditures are larger than those of private ones. On the other hand, the findings are in contrast with those of Halıcı-Tülüce *et al.* (2016), who have concluded that private health expenditures have a negative effect on economic growth among high-income countries.

Table 13: System GMM Estimations for OECD Countries: Health Expenditures

		MODEL A			MODEL B				
Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln(y_{it-1})$		-0.088*** (0.020)	-0.137*** (0.028)	-0.212*** (0.054)	-0.092*** (0.030)	-0.137*** (0.040)	-0.093*** (0.034)	-0.088** (0.037)	-0.145*** (0.031)
$\ln(s_{kit})$			0.260*** (0.054)	0.267*** (0.093)	0.272*** (0.033)	0.258*** (0.046)	0.259*** (0.049)	0.191*** (0.046)	0.228*** (0.053)
$\ln(n_{it} + \omega + \delta_{it})$			0.016 (0.037)	0.061 (0.052)	-0.001 (0.019)	0.031 (0.043)	0.049 (0.037)	0.056* (0.032)	0.015 (0.041)
$\ln(mpc_{hit})$				0.064* (0.034)					
$\ln(PRIVATE_{it})$					0.092** (0.042)				
$\ln(POCKET_{it})$					0.007 (0.064)				
$\ln(x_{hit})$							-0.054 (0.091)		
$\ln(PUBLIC_{it}/GDP_{it})$								-0.116* (0.062)	
$\ln(PUBLIC_{it})$									0.143 (0.153)
Constant		0.983*** (0.213)	0.669** (0.310)	1.303** (0.584)	-0.120 (0.408)	0.617 (0.580)	0.285 (0.288)	0.487 (0.352)	0.242 (0.558)
Implied λ (%)		3.07%	4.93%	7.92%	3.20%	4.91%	3.24%	3.06%	5.21%
AR(1)		0.018	0.016	0.019	0.016	0.017	0.019	0.012	0.020
AR(2)		0.099	0.130	0.419	0.150	0.173	0.119	0.155	0.132
J-stat.		0.487	0.286	0.199	0.288	0.373	0.294	0.190	0.217
C-stat.		0.856	0.913	0.710	0.906	0.810	0.615	0.624	0.641
# of instruments		20	27	33	34	33	32	33	34
# of groups		38	38	38	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rate. J-stat. and C-stat. show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values of the z-test statistics that show serial correlation of order $AR(k+1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Table 14: System GMM Estimations for OECD Countries: Health Expenditures and the Government

	MODEL A			MODEL B		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$						
$\ln(y_{it-1})$	-0.194*** (0.053)	-0.096** (0.042)	-0.172*** (0.058)	-0.137*** (0.051)	-0.178*** (0.052)	-0.171*** (0.060)
$\ln(s_{it})$	0.266*** (0.082)	0.152*** (0.052)	0.240*** (0.071)	0.242*** (0.073)	0.234** (0.082)	0.199*** (0.046)
$\ln(n_{it} + \omega + \delta_{it})$	0.049 (0.047)	-0.090* (0.050)	0.041 (0.045)	0.045 (0.093)	0.069 (0.063)	0.036 (0.040)
$\ln(mpc_{H_{it}})$	0.045 (0.037)					
$\ln(PRIVATE_{it})$		0.059 (0.077)				
$\ln(POCKET_{it})$			-0.125 (0.102)			
$\ln(x_{H_{it}})$				0.080 (0.173)		
$\ln(PUBLIC_{it}/GDP_{it})$					0.217* (0.116)	
$\ln(PUBLIC_{it})$						0.216 (0.129)
$\ln(1 - \tau_{it})$	-0.029 (0.091)	-0.057 (0.072)	0.052 (0.090)	0.099 (0.191)	0.403 (0.390)	0.150 (0.241)
$\ln(\tau_{it})$				0.055 (0.124)	0.251 (0.274)	0.165 (0.202)
Constant	1.276 (0.760)	0.802 (0.853)	1.207 (0.896)	-0.145 (1.357)	-1.837 (2.732)	-0.950 (1.794)
Implied λ (%)	7.20%	3.38%	6.28%	4.91%	6.54%	6.26%
AR(1)	0.021	0.033	0.019	0.020	0.054	0.026
AR(2)	0.249	0.013*	0.291	0.292	0.756	0.149
J-stat.	0.150	0.195	0.145	0.266	0.435	0.193
C-stat.	0.234	0.443	0.177	0.650	0.860	0.683
# of instruments	31	31	31	30	30	36
# of groups	37	37	37	37	37	37

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rate. J-stat. and C-stat. show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values of the z-test statistics that show serial correlation of order $AR(k+1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively. ^a In this case, the instrument set is restricted to lags 4 and longer to avoid using lower-level lags as invalid instruments. As a result, the p -value for AR(3) is obtained as 0.255.

Table 15: System GMM Estimations for OECD Countries: Health Expenditures, the Government, and Control Variables

	MODEL A			MODEL B		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$						
$\ln(y_{it-1})$	-0.144** (0.057)	-0.151*** (0.045)	-0.148*** (0.055)	-0.123*** (0.044)	-0.148** (0.071)	-0.138*** (0.046)
$\ln(s_{kit})$	0.277** (0.062)	0.266*** (0.053)	0.272*** (0.055)	0.302*** (0.057)	0.234*** (0.053)	0.246*** (0.056)
$\ln(\pi_{it} + \omega + \delta_{it})$	0.018 (0.068)	-0.029 (0.044)	-0.015 (0.081)	0.050 (0.095)	0.098 (0.130)	0.039 (0.102)
$\ln(mpc_{hit})$	0.016 (0.033)					
$\ln(PRIVATE_{it})$		0.024 (0.055)				
$\ln(POCKET_{it})$			-0.079 (0.083)			
$\ln(x_{hit})$				-0.037 (0.101)		
$\ln(PUBLIC_{it}/GDP_{it})$					0.052 (0.116)	
$\ln(PUBLIC_{it})$						0.069 (0.090)
$\ln(1 - \tau_{it})$	-0.010 (0.089)	-0.077 (0.073)	0.016 (0.073)	-0.034 (0.115)	0.189 (0.227)	0.058 (0.094)
$\ln(\tau_{it})$				-0.016 (0.085)	0.106 (0.160)	0.044 (0.068)
$\ln(HC_{it})$	-0.017 (0.016)	-0.013 (0.018)	-0.024 (0.016)	-0.014 (0.016)	-0.030 (0.019)	-0.029 (0.017)
$\ln(OPEN_{it})$	0.006 (0.006)	0.013 (0.005)	0.009 (0.006)	0.008 (0.006)	0.001 (0.003)	0.002 (0.003)
Constant	0.714 (0.808)	1.097 (0.755)	0.981 (0.786)	0.616 (0.774)	-0.503 (1.515)	0.012 (0.769)
Implied λ (%)	5.18%	5.47%	5.35%	4.37%	5.34%	4.93%
$AR(1)$	0.019	0.006	0.020	0.016	0.032	0.015
$AR(2)$	0.169	0.877	0.366	0.352	0.397	0.141
J -stat.	0.290	0.405	0.245	0.207	0.232	0.395
C -stat.	0.983	0.493	0.835	0.348	0.759	0.908
# of instruments	34	34	34	30	30	30
# of groups	37	37	37	37	37	37

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rate. J -stat. and C -stat. show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. $AR(1)$ and $AR(2)$ are the p -values for the z -test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Table 16: System GMM Estimations for LDCs: Health Expenditures

	MODEL A					MODEL B			
Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\ln(y_{it-1})$	0.173** (0.077)	0.185* (0.106)	-0.005 (0.071)	0.038 (0.057)	0.017 (0.051)	0.028 (0.062)	0.045 (0.085)	-0.038 (0.070)	-0.067 (0.075)
$\ln(s_{kit})$		0.183*** (0.055)	0.228*** (0.047)	0.245*** (0.046)	0.257*** (0.047)	0.299*** (0.061)	0.325*** (0.063)	0.278*** (0.056)	0.248*** (0.059)
$\ln(n_{it} + \omega + \delta_{it})$		0.047 (0.144)	-0.036 (0.101)	-0.018 (0.103)	-0.015 (0.102)	0.055 (0.096)	0.055 (0.119)	-0.014 (0.087)	-0.182 (0.162)
$\ln(mpc_{Hit})$			-0.112** (0.055)						
$\ln(PRIVATE_{it})$				-0.065 (0.072)					
$\ln(POCKET_{it})$					-0.053 (0.069)				
$\ln(x_{Hit})$						-0.017 (0.060)			
$\ln(PUBLIC_{it}/GDP_{it})$							0.037 (0.076)		
$\ln(PUBLIC_{it})$								0.100 (0.084)	
$\ln(EXTERNAL_{it})$									-0.075* (0.042)
Constant	-1.293** (0.598)	-2.078** (0.908)	-0.586 (0.622)	-0.739 (0.615)	-0.669 (0.500)	-1.204* (0.622)	-1.455* (0.748)	-0.823 (0.567)	0.402 (0.754)
Implied λ (%)	-5.31%	-5.67%	0.15%	-1.25%	-0.56%	-0.91%	-1.48%	1.28%	2.29%
AR(1)	0.217	0.143	0.144	0.122	0.115	0.089	0.110	0.143	0.154
AR(2)	0.268	0.946	0.966	0.891	0.887	0.878	0.908	0.828	0.899
J-stat.	0.324	0.618	0.294	0.140	0.205	0.312	0.146	0.182	0.538
C-stat.	0.133	0.151	0.447	0.179	0.448	0.365	0.401	0.307	0.307
# of instruments	14	18	30	30	30	30	30	30	30
# of groups	34	34	34	34	34	34	34	34	34

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rate. J-stat. and C-stat. show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values for the z-test statistics that show serial correlation of order $AR(k+1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Table 17: System GMM Estimations for LDCs: Health Expenditures and the Government

	MODEL A			MODEL B		
Dependent variable: $\ln(y_{it}) - \ln(y_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)
$\ln(y_{it-1})$	-0.108* (0.061)	-0.111*** (0.039)	-0.130*** (0.033)	-0.001 (0.095)	-0.049 (0.078)	-0.008 (0.069)
$\ln(s_{kit})$	0.314*** (0.108)	0.279*** (0.082)	0.287*** (0.105)	0.205* (0.104)	0.337*** (0.121)	0.192** (0.081)
$\ln(n_{it} + \omega + \delta_{it})$	-0.251 (0.185)	-0.227* (0.125)	-0.275* (0.161)	-0.265 (0.178)	-0.206 (0.153)	-0.203 (0.141)
$\ln(mpc_{hit})$	-0.022 (0.066)					
$\ln(PRIVATE_{it})$		0.057 (0.049)				
$\ln(POCKET_{it})$			0.084** (0.039)			
$\ln(x_{hit})$				-0.262** (0.113)		
$\ln(PUBLIC_{it}/GDP_{it})$					-0.175* (0.092)	
$\ln(PUBLIC_{it})$						-0.121*** (0.033)
$\ln(1 - \tau_{it})$	-0.025 (0.142)	-0.030 (0.125)	-0.051 (0.117)	-0.037 (0.233)	-0.017 (0.242)	0.003 (0.192)
$\ln(\tau_{it})$				0.036 (0.156)	0.061 (0.148)	0.124 (0.116)
Constant	0.533 (1.052)	0.436 (0.789)	0.670 (0.756)	0.465 (1.867)	-0.305 (1.854)	-0.108 (1.486)
Implied λ (%)	3.82%	3.91%	4.65%	0.03%	1.66%	0.28%
AR(1)	0.144	0.127	0.153	0.254	0.216	0.341
AR(2)	0.784	0.621	0.468	0.459	0.531	0.602
J-stat.	0.395	0.447	0.150	0.604	0.539	0.344
C-stat.	0.301	0.375	0.150	0.604	0.539	0.344
# of instruments	21	21	16	18	18	18
# of groups	21	21	21	21	21	21

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). Implied λ shows the estimated convergence rate. J-stat. and C-stat. show the p -values for the Hansen and difference-in-Hansen test statistics, respectively. AR(1) and AR(2) are the p -values for the z-test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

For LDCs, the results indicate that (i) the share of private health expenditures in total income and the share of external health expenditures in total health expenditures have a negative and significant impact on long-run income growth, (ii) public health expenditures are negatively and significantly related to the growth rate of per capita income if the regressions are further controlled by the effects of income taxation, (iii) personal health expenditures of the households proxied by the share of out-of-pocket expenditures in total health expenditures have a positive and significant impact on long-run growth, and (iv) the negative impacts of public health expenditures are larger than those of private ones. Once more, the result on the negative effects of private health spending is in line with the results of Halıcı-Tülüce *et al.* (2016), but the finding on the negative effects of public health spending is in contrast with the results of Gyimah-Brempong and Wilson (2004) and Halıcı-Tülüce *et al.* (2016). Lastly, the results of the study provide support to the findings of some previous studies on low-income countries, which have found evidence of income divergence (Akinbode *et al.*, 2021; Eggoh *et al.*, 2015) and also no evidence of any convergence or divergence among low-income countries (Aboubacar and Xu, 2017).

2.6. CONCLUDING REMARKS AND POLICY IMPLICATIONS

This chapter investigates the nexus between health expenditures and economic growth by highlighting the effects of personal and public health spending on economic growth. To this end, first, the chapter develops two augmented Ramsey models in which both total consumption and total government spending are subject to a key division between health and non-health consumption. In other words, in a Ramsey economy with a government and an endogenous consumption-savings trade-off, I first assume that all health expenditures are met by the personal health expenditures of the households. Then, I expand the first model by including public health spending, which is further financed by distortionary income taxes. In the first model, representative households obtain utility by consuming health and non-health goods and services, while in the second model, public health goods and services also enter the felicity function of the households. On the other hand, the first model assumes that personal health spending generates a positive externality on the total labor force of the economy,

whereas this externality is generated by public health spending in the second model. Additionally, each model assumes the existence of positive population growth and technological progress. I also provide a few extensions to both models to make them partly comparable. For each setup, the solutions for both market and social planner equilibria are provided in the study.

The chapter further derives two augmented Solow models to empirically examine the impact of health expenditures on income growth and the convergence process. Both models follow the assumptions of the Ramsey models given above as far as the theoretical framework allows. As in the Ramsey models, the first model assumes that personal health spending drives total economic health expenditures, whereas the second model assumes that all expenditures are provided by the government. In parallel to the Ramsey models, the first model considers the externality effect of personal health expenditures, while the latter deals with the externality of public health spending. Similar to the Ramsey models, in each augmented Solow model, I assume that there is a government that collects income taxes in an effort to provide some public goods and services to the economy. Of course, in contrast to the Ramsey models, these model economies assume an exogenous consumption-savings trade-off. However, each model endogenizes both personal and public health expenditures by assuming that they take a constant share from disposable and total income, respectively. Hence, each model provides a theory-backed conditional income convergence equation to be used in the empirical part of the chapter.

Following the above, the empirical part of the chapter provides system GMM estimates of two formal income convergence equations that are tested for two different country groups over a 20-year period. In other words, the analyses include both OECD members and LDCs, which are quite different in terms of both income levels and the health care models adopted. The study uses several indicators to proxy for health expenditures. To proxy for personal health expenditures, the study employs the percentage share of out-of-pocket health expenditures in total health expenditures and the percentage shares of per capita private health expenditures in real per capita income and total health expenditures. Moreover, to proxy for public health spending, the study uses the percentage shares of government health expenditures in total government expenditures, total GDP, and total health expenditures. The analyses also include the

percentage share of external health expenditures in total health expenditures, which is quite high for LDCs compared to OECD members. Lastly, the income tax rate as a fiscal policy variable implied by the theoretical models and the human capital index and openness to trade as additional control variables are also included in the analyses.

The results of the Ramsey models are as follows: In the presence of production externalities, the results of both models exactly reflect the dual role of health expenditures in an economy. In this sense, the findings of the first model show that an increase in the relative share of personal health consumption raises capital accumulation, the wage rate, and disposable income through its positive effects on labor productivity. This in turn leads to an increase in the total consumption opportunities for the households, including the consumption of health and non-health goods and services, and hence an increase in their welfare. However, each increase in personal health spending also lowers consumption of non-health goods and services, including housing, education, and other basic household needs. Therefore, in the model, the net effect of health consumption on the consumption of other goods and services depends both on the size of its externality and on its relative share in total consumption. Moreover, the results of the first model show that both the income tax rate and the population growth rate have a negative effect on all the long-run equilibrium values of the model variables.

On the other hand, the results of the second model show that an increase in the share of public health expenditures raises long-run capital accumulation and total income, given the existence of the production externality generated by public health spending. Due to the same reason, the findings show that the destructive effects of income taxation are lessened in the second model compared to the first one. Therefore, public health spending causes two competing effects depending on the size of the tax rate and externality: It leads to (i) a reduction in capital accumulation, the wage rate, and disposable income through income taxation and (ii) an increase in capital accumulation and disposable income through its positive effects on labor productivity, which in turn gives households greater access to all goods and services they consume and thereby increases their welfare. However, as there still exists a trade-off between personal health and non-health consumption, the existence of public health spending allows consumers to spend more on non-health goods and services and raises the share

of non-health consumption in total consumption compared to the first model. Lastly, although the above discussions are based on market solutions, socially optimal solutions to the models further show that in the presence of public health spending, the long-run savings rate is not free from the share of households' consumption of personal health.

In the absence of externalities, the results of the Ramsey models indicate that the two models produce exactly the same long-run values for physical capital, total output, and total consumption. Therefore, in the absence of production externalities, the inclusion of public health services in an individual's welfare function only affects the level of health and non-health consumption at the expense of lower capital accumulation and total output compared to the above model with externalities. However, in this case, the existence of public health expenditures directly lowers the long-run value of personal health consumption in favor of households and raises the value of non-health consumption compared to the first model. Of course, as in the above models, this favor cuts down on the government resources necessary to be used in other sectors of the economy where the government is engaged. Additionally, the values of all macroaggregates are directly and negatively affected by the existence of the income tax rate in the absence of the externality generated by public health spending. Lastly, in each model without externalities, the long-run values of capital, income, and total consumption are all lower than the values obtained from the solution of the basic Ramsey model with technological progress due to income taxation.

Overall, the results of the Ramsey models imply that technological progress is a crucial driver of both personal and public health expenditures in the long run, which is in line with the findings of Newhouse (1992), Okunade and Murthy (2002), Jones (2002), and Lorenzoni *et al.* (2019), among others. Second, in each case, an increase in income through increases in productivity leads households to begin consuming more again. This leads to an increase in welfare but also raises concerns on both household and government budgets due to unavoidable increases in health care spending (Bloom and Canning, 2000; Hall and Jones, 2007). Third, the inclusion of government in the provision of public health goods and services raises the level of personal health and non-health consumption. It further allows households to spend more on non-health consumption by raising their consumption possibilities. Heuristically speaking, under

the assumption of gross substitutability between health and non-health consumption, public health expenditures help households establish a more balanced trade-off between the quantity of life and the quality of life.¹⁰³ On the other hand, there is always a direct trade-off between the resources allocated to health and non-health uses. Therefore, especially in the absence of production externalities, each resource used for public health services directly lowers long-run capital accumulation and total output and thereby puts pressure on the budgets of all actors in an economy. Moreover, as in the case of personal health spending, each unit of consumption devoted to health lowers the resources used for non-health consumption and, so to speak, lowers the quality of life for households.

On the other hand, the theoretical results of the Solow models show that both personal and public health expenditures grow at the rate of technological progress in the long run. For the first model with personal health spending, the findings indicate that the long-run savings rate is negatively (positively) affected by the increases (decreases) in the share of personal health expenditures in total disposable income. Following that, although each increase in MPC for health raises capital accumulation, total output, and disposable income in the long run, its positive effects on these aggregates are restricted depending on the relative sizes of the two ratios: the ratio of the savings rate over MPC for health and the ratio of the elasticities of physical capital and personal health expenditures with respect to output. However, the second Solow model shows that increases in the share of public health spending directly raise all steady-state values of the model variables. Furthermore, given the positive effects of public health services on labor productivity, the negative effects of the income tax rate clearly decrease compared to the first model. The model further implies that the income tax rate should be chosen to be equal to the output share of the effective labor

¹⁰³ This argument originates from the assumption that health expenditures directly increase the health level of individuals. Most of the studies in the related literature assume that there is a one-to-one relationship between expenditures on health and good health status. In empirical terms, several studies have found a positive and significant relationship between health spending and health status (Anyanwu and Erhijakpor, 2009; Gupta *et al.*, 1999; Jaba *et al.*, 2014; Nixon and Ullmann, 2006; Novignon *et al.*, 2012). On the other hand, there are others that have argued that the contribution of health spending to health status as measured by life expectancy or infant and child mortality is either small or statistically insignificant (Filmer and Pritchett, 1997; Musgrove, 1996). This discussion is outside the scope of this study. However, given that these expenditures are a significant part of health production, this study implicitly assumes that the main reason for incurring health expenditures is to enhance the health status of the individuals and to compensate for any health decay.

force in order to optimize long-run public health expenditures. Moreover, in this case, although the long-run savings rate becomes free from the adverse effects of personal health spending, public spending on non-health goods and services becomes highly limited.

Finally, the Solow models provide two conditional income convergence equations that empirically show the contribution of health expenditures to long-run income growth and the convergence process. Following that, the empirical findings of the chapter are as follows: First, the results of the system GMM estimations provide support for absolute and faster conditional income convergence among structurally similar OECD members, in line with the findings of the convergence literature. However, among LDCs, the findings indicate evidence of absolute and faster conditional income divergence. Second, regarding the regressions with health expenditures, the findings indicate that only private health expenditures have a significant effect on income growth among both country groups. However, while private contributions have a positive effect on income growth among OECD members, their effects are negative for LDCs. Furthermore, while private health expenditures positively contribute to the convergence among OECD countries, for LDCs, there is no evidence of any convergence or divergence over a 20-year period. Additionally, the results further show that public health expenditures significantly lower long-run income growth and decelerate the speed of convergence among OECD members. On the other hand, while public health spending has no significant effect on the growth rate of LDCs, external health expenditures have a significant and surprisingly negative effect on income growth.

Third, after the inclusion of income tax indicators, the findings show that public health expenditures become significant for both country groups. In this sense, the findings indicate that public health expenditures positively and significantly affect income growth and accelerate the speed of convergence among OECD members. However, for LDCs, increasing the share of public health expenditures significantly lowers the growth rate of per capita income, but there is still no evidence of any conditional convergence. Moreover, the findings for LDCs show that after controlling income tax, the share of out-of-pocket health expenditures becomes significant in explaining income growth and the convergence process. In other words, for this

country group, increases in out-of-pocket health expenditures of households have a positive effect on income growth and allow LDCs to close their income gaps at a higher rate of about 4.7% per annum. Lastly, in each case, while the population growth rate is not related to long-run income growth, the savings rate has a highly significant and positive effect on per capita income growth for both country groups.

Based on the above results, the chapter has the following policy implications: To begin with, the theoretical findings of the study show that health expenditures are crucial to raise total output, non-health consumption, and thus individual welfare through their positive effects on labor productivity. On the other hand, these expenditures constitute a significant cost for both individuals and society, and hence, any decrease in health spending increases the resources left for other uses. However, because these expenditures are unavoidable in order to produce health, one policy suggestion might be to increase not the size but the efficiency of the health care sector and its expenditures in national economies. Second, under the gross substitutability between health and non-health consumption, public support is always required for individuals to establish a more balanced trade-off between the quantity of life and the quality of life.

Although this favor to individuals reduces the amount of public resources necessary to be used in other sectors of the economy, it will simultaneously and significantly raise the level of non-health consumption and labor productivity in a country. Furthermore, the coexistence of personal and public health expenditures lowers the pressure on the budgets of all actors in an economy. Third, the findings of the study show that increases in income through increases in labor productivity and, more importantly, increases in technological progress are crucial drivers of health consumption in the long run. This means that, particularly in high-income countries, concerns about the severe burden on government budgets caused by perpetual increases in health spending will continue in the near future. On the other hand, for countries with low resources, there may be a need for increasing public resources to free up individual budgets and take advantage of the positive effects of these expenditures on labor productivity.

The empirical results by country groups show that private contributions, which include the contributions of households, corporations, and non-profit organizations,

were doing well over a 20-year period in the OECD group. That is, private health expenditures have a significant and positive impact on long-run income growth and the convergence process among OECD countries. However, for this country group, the growth effects of public health spending are ambiguous and call for future research given the serious concerns about government budgets caused by an increase in NCDs and population aging among OECD members. In this sense, the major NCDs account for about 60% of total health spending in the OECD (OECD, 2016). Furthermore, aging and thereby the dependent population have significantly increased in recent decades, and the share of the population aged 65 years and over has nearly doubled across all OECD members (OECD, 2021). Additionally, the OECD (2020b) report shows that the costs for long-term care, which are met by either government spending or through compulsory insurance, have significantly increased in most OECD members.

Given the above issues facing OECD members and the empirical findings of this study, the policy implications are not straightforward and do not directly impose a private or public option. Nonetheless, one may seriously suggest that policy-makers in these countries should focus on planning the extent to which increased health spending in the future should be financed from personal or public sources, each of which is not cost- and hassle-free. The success of private contributions, the trade-off between the quality and quantity of life for individuals, competing demands for government resources, and the burden of taxes should be seriously considered in that choice. Furthermore, raising public awareness about promoting healthier lifestyles and more efficient use of health resources, particularly for those that have the potential to increase productivity, will be influential in lowering health care costs in addition to raising the efficiency of the health care sector in OECD members.

For LDCs, the conditions are much different than those of OECD members. The empirical findings using LDC data indicate that health expenditures from all financing sources, even surprisingly external ones, have a negative effect on long-run economic growth. Moreover, the findings show that only out-of-pocket health expenditures of individuals, which are the primary source of health care financing in most LDCs, positively contribute to income growth and the convergence process. This means that only individual efforts positively contributed to spending on health and

thereby to health production in this country group during the previous 20-year period. Given the theoretical results of the study, one policy implication for this country group appears to be raising public backup in health spending to depressurize individual budgets and thereby enhance both the quality and quantity of life for the people in LDCs. Although the empirical findings indicate that public health expenditures have a negative impact on income growth, this finding may arise due to the inefficient use of highly scarce resources in these countries. Therefore, developing a comprehensive national health policy and strategy in these countries and ensuring its effective implementation may be supportive of raising health spending and exploiting its positive effects on labor productivity, which in turn enhance long-run income growth. Additionally, imitating the success of OECD countries in private expenditures may also be helpful for LDCs.

The findings of the study further indicate that controlling for health expenditures in the analyses does not lead to any evidence of convergence among the sample countries in this group, while in fact there exists a significant divergence among LDCs if one relies on traditional determinants of income growth. Therefore, one may easily argue that it is impossible for these countries, which include low- and lower-middle-income countries of the WB, to converge with each other and thereby with high-income countries as long as they maintain their current economic practices. In this sense, one more interesting finding from the study is that, as a conventional driver of long-run income growth, the average savings rate is quite high in LDCs as compared to OECD members, and it has a highly significant and positive impact on income growth among LDCs. Therefore, policy-makers in these countries should primarily foster policies that will support income growth and convergence through (i) enabling the diffusion of technology among these countries, (ii) directing these relatively higher capital investments to the more appropriate areas that will ensure lower economic vulnerability in these countries, and (iii) using a share of these investments as investments in health to promote population health status and thereby enhance human assets and capabilities.

All in all, for high-income OECD countries with relatively better health outcomes, the issue seems to remain the serious increase in health expenditures. In other words, in this country group, the bulk of health spending is financed by private

or public contributions. Given the results of the study, it seems that increased pressure on public budgets due to a rise in NCDs and the aging of the population will remain a serious public issue in the coming years. Moreover, the OECD (2021) has pointed out that in 2020, during the COVID-19 pandemic, there was a sharp increase in total health spending of about 4.7% that corresponds to the highest rise in health expenditures in around 15 years. Therefore, given that increases in both income and poor health are among the main drivers of rising health spending, policy-makers in OECD members may need to take serious measures as given above. These measures will help to lower the enormous rise in the size of the health care sector and prevent health expenditures from becoming a substitute for both the growth and welfare prospects of these countries. Furthermore, the findings from the OECD sample seriously call for future research on the growth effects of public health spending.

On the other hand, for LDCs with relatively poor health and economic status, the problem is to both raise health expenditures and lower the pressures on their budgets at the same time. In LDCs, the level of population health status is still quite below that in high-income countries. Therefore, increasing spending on health is necessary to enhance the health level of the population, to be productive at all, and thereby to boost income growth with the size of the health care sector in contrast to OECD members. In other words, expenditures on health are instrumental and critical to realizing the potential of the productive human capital embodied in the populations of these countries. However, in these countries, expenditures on health and thereby health capital are primarily produced by household consumption and, secondarily, by means of spending made by the government at the cost of taxation. Additionally, in LDCs, diseases such as HIV, tuberculosis, and malaria still threaten the bulk of the population and cause death and disability (WHO, 2017). Recently, these countries have further faced serious indirect effects of the pandemic, such as increased government and individual spending on health (UN, 2020). Therefore, in LDCs with poor health and a weak economic base, health expenditures continue to constitute a serious burden and need for both individuals and governments.

Following the above, the results of this study further show that there was a significant divergence in the income levels of LDCs during the previous 20-year period. Moreover, as indicated by the UN (2021) report, familiar development

challenges also make it harder to close the gap between LDCs and other country groups. Hence, given the results of the study, one could argue that there is an urgent need in these countries (i) to direct capital investments in a more accurate and efficient manner in order to raise income levels and push convergence and (ii) to effectively use a portion of this income as health spending in order to cover the majority of the population. Otherwise, the long-run growth prospects for these countries may virtually disappear as long as current practices continue to be implemented. Lastly, external aids are an integral part of the economic and health care systems of LDCs with limited economic resources. For instance, during the pandemic, 23 billion US dollars have been spent by international collaborators to support universal health care in LDCs (UN, 2021). Although these contributions are all crucial and necessary for LDCs, the findings show that they seem not capable of leading to sustainable long-run income growth. Therefore, future research is needed to further investigate the impact and effectiveness of both public and external health expenditures in LDCs.

CHAPTER THREE

A DRIVER FOR HEALTH DECAY: NO THEORY JUST EVIDENCE

“There is something desperately wrong with our health-care systems and with our societies when, in this amazingly rich world, there is still so much ill health ... there are such enormous differences between the rich and the poor. Hunger is of endemic proportions; obesity too. But the latter gets so much more attention as it is a disease of the affluent ...”.

Mooney (2012: 3)

3.1. INTRODUCTION

The global prevalence of obesity has remarkably increased over the last four decades, rising from 4.7% in 1975 to 13.1% in 2016.¹⁰⁴ It not only causes physical disabilities, but it also increases the risk of developing a number of NCDs, which account for more than 70% of all global deaths each year, according to the WHO's (2020b) report. In addition to being one of the main metabolic risk factors for developing a NCD, obesity significantly raises health care costs for individuals and society through lower productivity and lower income growth due to absenteeism, presenteeism, premature death, and long-term disability.¹⁰⁵ The global economic burden of obesity is estimated to be around \$2.0 trillion, or 2.8% of GDP, which includes the costs of lost productivity and health care to mitigate the effects of obesity (Dobbs *et al.*, 2014). Once considered a high-income country problem, it has now become more common in many middle- and low-income countries. Figure 5 depicts the prevalence rates of adult obesity for both sexes for all world countries and income groups from 1975 to 2016.

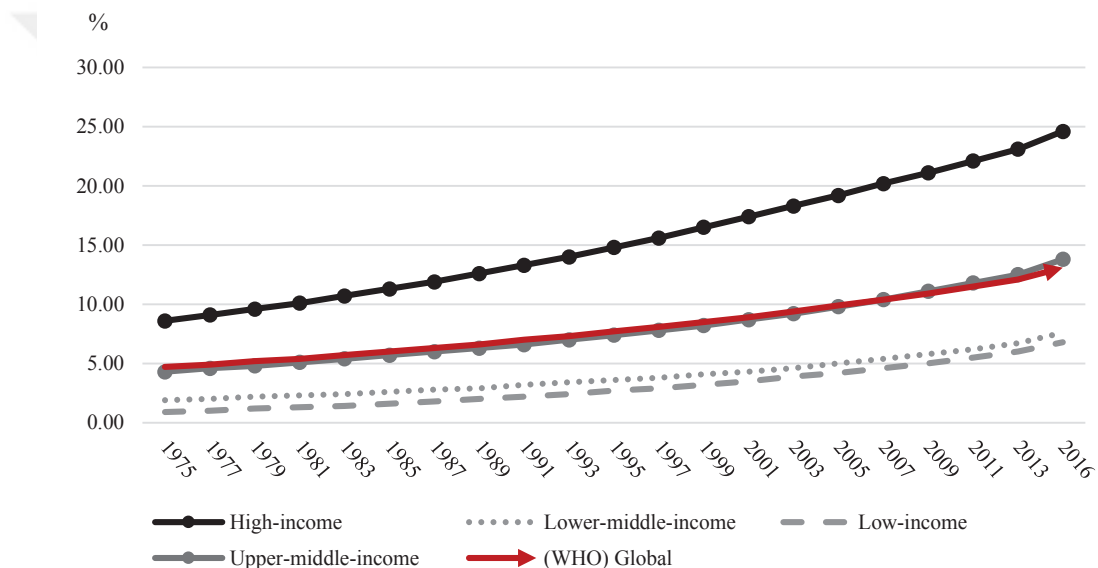
According to the figures, over a 42-year period, the prevalence of adult obesity increased around the world and across income groups. For instance, in low-income countries, adult obesity prevalence increased from 0.9% in 1975 to 6.8% in 2016, with an average growth rate of about 15.6% per year. In lower-middle-income countries, these rates were 1.9% in 1975 and 7.6% in 2016. On the other hand, despite these

¹⁰⁴ The data was obtained from the age-standardized estimates of the WHO on the prevalence of obesity among adults (WHO, 2022a).

¹⁰⁵ Please see Tremmel *et al.* (2017) for a detailed systematic literature review on the economic burden of obesity.

continued increases in the sample period, the adult obesity rates of low- and lower-middle-income countries remained below the global rates shown by a red line with an arrow. In addition, adult obesity rates in upper-middle-income countries exhibit a parallel trend to the global pattern over the sample period. In this sense, in upper-middle-income countries, the observed prevalence rates of adult obesity were 4.3% in 1975 and 13.8% in 2016, which are quite close to the global rates given above. However, the obesity rates of high-income countries were enormously different from the rates observed in other income groups and on a global scale.

Figure 5: Adult Obesity Prevalence by Income Groups and on a Global Scale

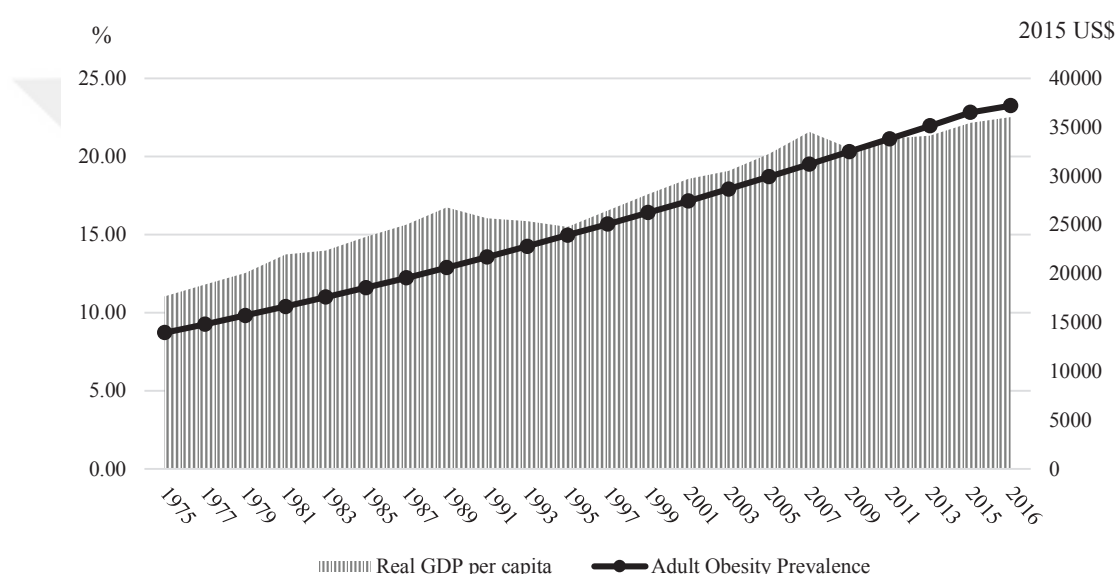


Source: The Global Health Observatory (GHO) of the WHO (2022a).

Figure 5 also shows that in high-income countries, prevalence rates of obesity among adults rose from 8.6% in 1975 to 24.6% in 2016. Additionally, in each year of the 42-year period, these countries clearly had the highest obesity rates by a landslide compared to other income groups. If one focuses on a particular high-income or developed country group, such as OECD countries, these figures do not change much, as shown in Figure 6 below. In this context, Figure 6 illustrates the evolution of adult obesity prevalence in both sexes, shown in the left-vertical axis, and real per capita income, shown in the right-vertical axis, for the average of 38 OECD countries over the period 1975-2016. According to the graph, the obesity rates in the OECD group

increased seriously and steadily from 8.72% in 1975 to 23.25% in 2016. Parallel to that, real income per capita also increased over the same period, following a bumpier pattern. Of course, although adult obesity rates are high in all member countries, they have not remained at the same level over the 42-year period. In this sense, Figure 7 below shows the average obesity rate for the OECD group over the 42-year period and the top 18 OECD members with obesity rates above the OECD average, which is shown by a dashed black line.

Figure 6: Real GDP per capita and Adult Obesity Prevalence in the OECD

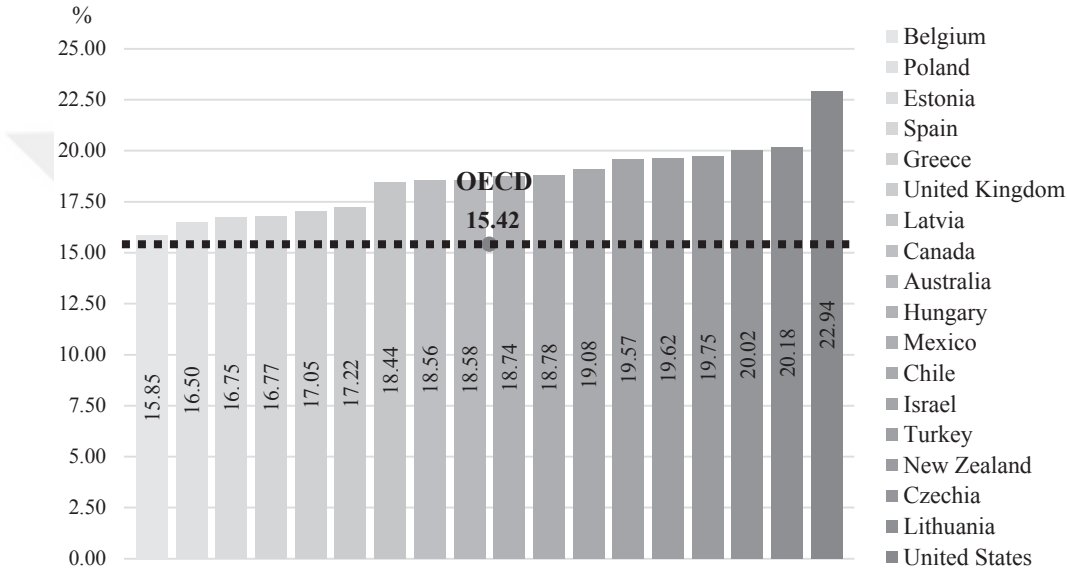


Source: The GHO of the WHO (2022a) and the WDI of the WB (2022).

Figure 7 indicates that 18 OECD members shown in the right-vertical box had obesity rates above the OECD average of 15.42%. In terms of 42-year averages, the U.S. had the highest average, with a rate of about 22.94%, while Belgium had the lowest rate of around 15.85%. All other 20 members were below the OECD average. Moreover, there are two member countries with extremely low obesity rates: Japan and the Republic of Korea. In this sense, the average adult obesity rate was 2.12% in Japan and 2.42% in Korea over the period 1975-2016. However, in overall terms, most OECD members suffer from serious increases in the prevalence rates of adult obesity. According to the OECD's (2019a) report, the rates of obesity among adults are still high and on the rise in almost all OECD member states, having climbed to 58% of the

adult population across OECD countries. In 2016, more than one in five adults (23.2%) and three adults (35.1%) were obese and pre-obese in OECD countries, respectively (OECD, 2019a). Moreover, the estimated costs related to obesity range between 0.5% and 1.6% of GDP among OECD countries, and annual health care costs up to 425 billion dollars (PPP) have been found in obesity-related studies considering OECD, Group of 20 (G20), and EU28 countries (OECD, 2019a).

Figure 7: Top 18 OECD Members: 1975-2016 Average Obesity Rates



Source: The calculations of the author. The raw data were from the GHO of the WHO (2022a).

In brief, obesity continues to remain one of the most serious public health challenges in the OECD region. It is not just a medical issue but also a public health crisis triggered by economic factors. In this context, this chapter aims to examine the link between weight-related health, proxied by adult obesity, and income growth in an empirical neoclassical growth framework by relying on a Barro-regression approach.¹⁰⁶ To this end, two separate empirical models are employed in the study. In other words, this chapter first tests the hypothesis of obesity convergence among 38 OECD members and simultaneously investigates the economic determinants of the growth in adult obesity in both sexes. Then, the chapter examines the impact of adult obesity and its determinants, including real income per capita, income inequality,

¹⁰⁶ The details of the Barro-regression approach are provided in Chapter 1.

unemployment, and trade openness, on income growth and the income convergence process. Therefore, the study in this chapter builds on the related literature in several respects. In the related literature, there are only a limited number of macro-level studies that investigate the hypotheses of absolute and conditional obesity convergence among OECD members. In other words, previous studies on obesity convergence have either examined the hypothesis of club convergence (Kasman and Kasman, 2021; Nghiem *et al.*, 2018), absolute β -convergence (Kasman and Kasman, 2021; Li and Wang, 2016), conditional β -convergence (Duncan and Toledo, 2018a, 2018b), or spatial convergence (Alexiadis *et al.*, 2019) among OECD or EU members.

To my best knowledge, only the studies of Duncan and Toledo (2018a, 2018b) have analyzed absolute and conditional β -convergence in obesity among EU members by employing traditional cross-sectional tests. However, none of these related studies has examined this relationship by employing a more robust and dynamic panel data approach. In this sense, the methodological approaches of previous studies seriously suffer from heterogeneity and endogeneity bias. Therefore, this study significantly deviates from previous literature on obesity convergence in terms of the methodology employed. Moreover, the aforesaid studies have mostly used a subsample of OECD members in their analyses, namely EU countries. Hence, compared to previous studies, the study in this chapter significantly contributes to the limited and related literature by examining both absolute and conditional convergence in adult obesity among all 38 members of the OECD and by employing a more efficient dynamic panel data approach, system GMM. Furthermore, different from previous studies, the study investigates the determinants of the growth in adult obesity from a macro-level perspective by including real income per capita, Gini coefficients, the total unemployment rate, and openness to trade in the analyses.

In the second empirical model, the study tests the hypothesis of income convergence conditional on the savings rate, the population growth rate, the prevalence rates of adult obesity, the determinants of obesity growth given above, and the human capital index. To my best knowledge, there are only two macro-level studies in the literature that have empirically analyzed the impact of adult obesity on income growth and the convergence process for the states of the U.S. (Alexiadis and Eleftheriou, 2011) and for transition economies (Osmonbaeva, 2021) by using traditional OLS and

ARDL approaches. Therefore, from a macro perspective, this study further fills the gap in the related literature by examining the effects of adult obesity and its determinants on income growth and convergence among 38 OECD member countries. Additionally, as in the first model, the study adopts a system GMM approach, which has more superior features in terms of growth econometrics.¹⁰⁷ Lastly, compared to other related studies, all the analyses of the study employ relatively more recent data and a longer time period over the years between 1975 and 2016. In brief, examining the relationship between income, obesity, and its determinants by considering both income and obesity convergence among OECD member countries will (i) reveal important information for developing common preventive policies on this issue and (ii) provide guidance to institutions and policy-makers in enhancing regional integration in the health and economic policies of the member countries.

The main findings of the study provide clear evidence of absolute and faster conditional obesity convergence among the members of the OECD over the 42-year period. In line with the findings of previous studies, the findings of this study further state that real per capita income is one of the key drivers of obesity growth. That is, increases in income significantly raise the growth in the prevalence rates of adult obesity among OECD members, with an elasticity range between 0.03% and 0.05%. The findings further show that excessive weight gain is a greater problem for the unemployed in the OECD countries, implying that changes in income due to unemployment may lead individuals to health-demoting behaviors, *e.g.*, the replacement of a healthy diet. However, the magnitude of the effect of unemployment on obesity growth is almost negligible among high-income OECD members compared to other determinants of obesity growth.

Moreover, the empirical findings of the study further emphasize the significant role of income inequality on the income-to-health path. In other words, the results significantly indicate that more unequal societies within the OECD are more vulnerable to being obese. Lastly, more openness to trade is correlated with better weight-related health among OECD members. In other words, the results show that more openness to trade significantly lowers obesity growth among 38 members

¹⁰⁷ Please refer to Section 1.4.1.2 in Chapter 1 for a detailed explanation of the system GMM approach and its features.

through its health-promoting effects, *i.e.*, easy access to different kinds of medical supplies and good health practices. In addition, the findings of the study further show that the effects of per capita income and unemployment on obesity prevalence become insignificant when the estimations are controlled for inequality and openness to trade. In this regard, the results of the study may imply that income inequality and trade openness are more significant and strong determinants of obesity growth in OECD countries.

The findings from the second model that examines the link between income growth and adult obesity rates further indicate the evidence of absolute and faster income convergence among OECD countries, as expected. The results further show that, although insignificant, increases in adult obesity rates negatively affect income growth among the OECD group and lower the speed of income convergence. This finding may indicate that increases in obesity have negative but indirect effects on the growth rate of per capita income through other mechanisms such as absenteeism and presenteeism, which may not be well reflected by simple growth regressions as employed in this study. The results further show that among OECD members, the growth in per capita income is significantly fed by increases in its traditional driver, the savings rate.

Overall, the main policy implications from the study clearly suggest that policies aiming at a more equal distribution of income and more trade activities that lead to a more widespread diffusion of medical knowledge and good health practices, in line with public health efforts, are required to counteract the obesity epidemic in the OECD region. Furthermore, in line with the increases in the income levels in the region, public policies that will keep people away from excessive food consumption, lead to a healthier diet, and encourage more active lifestyles, such as encouraging more active travel patterns, should be implemented to slowdown the growth in adult obesity. Additionally, policy-makers should be aware that reducing unemployment could be effective in curbing the growth in adult obesity among the OECD group.

All in all, obesity continues to remain a serious public health issue among OECD members. According to the estimates of the OECD (2019a), in the next 30 years, this rise in obesity will cause around 220 million NCDs in member countries. Furthermore, particularly during the current COVID-19 outbreak, obesity needs more

serious efforts, as the outbreak may increase the risk of obesity even more due to the curfews and restrictions, which make access to healthy food, the environment for sufficient physical activity, and health-care services difficult. Moreover, obesity is a significant risk factor for individuals to experience severe COVID-19. In this sense, several studies on the linkage between obesity, NCDs, and COVID-19 have shown that COVID-19 patients with obesity are more severely affected than those without (Dicker *et al.*, 2020; Frühbeck *et al.*, 2020; Kluge *et al.*, 2020). The main findings of this study show that economic factors considerably explain the observed trends in obesity growth, in addition to other genetic and medical factors. In addition, obesity has considerable adverse impacts on population health, societies, and the economy, and it is expected that obesity and related diseases will reduce life expectancy by 0.9-4.2 years over the period 2020-2050 (OECD, 2019a: 21). Based on these findings, it appears that serious efforts, including a mix of policies that combine both economic and public health interventions, are required to reduce obesity growth among OECD members.

The organization of this chapter is as follows: Section 2 briefly reviews previous studies on the determinants of obesity, obesity convergence, and the link between obesity and income growth. Section 3 describes two empirical models to be estimated in the study and explains the main arguments of the empirical models. Section 4 presents the methodology, the data, and the empirical findings of the study. Section 5 concludes the chapter and discusses policy implications.

3.2. LITERATURE REVIEW

Over the past decades, economic drivers of obesity have been extensively investigated in the literature. In this context, several studies have focused on income as one of the main economic drivers of adult obesity. Some researchers have reported a positive link between obesity and income in the context of low-income countries (Egger *et al.*, 2012; Goryakin and Suhrcke, 2014; Pisa and Pisa, 2017). For example, Egger *et al.* (2012) have found a positive relationship between per capita income and adult body mass index (BMI) below a GDP of \$3000 for a sample of 175 countries and no significant relationship beyond this level. On the other hand, Minos (2016) has

reported that per capita income negatively relates to obesity rates among developing countries, while Lawson *et al.* (2016) have found that income is unrelated to male BMI in developing countries. However, in the context of high-income countries, several studies have found that increases in per capita income relate to higher weight gains and obesity (Bleich *et al.*, 2008; Lawson *et al.*, 2016; Loureiro and Nayga, 2005; Wang *et al.*, 2017). In addition to these studies that have investigated a linear link between income and obesity, a few scholars have argued that there is a non-linear relationship between the two variables. In this sense, a limited number of studies have examined the nexus between adult obesity and income in the context of the Obesity Kuznets Curve (OKC) hypothesis (Aydin, 2019; Grecu and Rotthoff, 2015; Windarti *et al.*, 2019). The results of OKC studies differ depending on the sample and the methodology used in the study, but most of them have reported the existence of an OKC in their studies.

For instance, Grecu and Rotthoff (2015) have shown evidence of an OKC for American white females, but there is no evidence for American white males. Similarly, Windarti *et al.* (2019) have discovered a clear OKC pattern for 130 countries from 1975 to 2010. On the other hand, Aydin (2019) has examined the nexus between obesity and income for the 20 most obese countries, ranging from the U.S. to Morocco, for the period 1991-2016. His findings have shown that the OKC hypothesis is invalid for most of the sample countries. Moreover, many researchers have argued that other economic factors other than income, which could be both a result and a cause of changing income levels, also contribute to increases in obesity prevalence. Some of these factors include income inequality (Grecu and Rotthoff, 2015; Offer *et al.*, 2010; Pickett *et al.*, 2005; Pisa and Pisa, 2017; Windarti *et al.*, 2019), international trade (Miljkovic *et al.*, 2015; Miljkovic *et al.*, 2018; Thow and Hawkes, 2009; Windarti *et al.*, 2019), urbanization (Goryakin and Suhrcke, 2014; Loureiro and Nayga, 2005; Minos, 2016; Windarti *et al.*, 2019), technological change (Goryakin and Suhrcke, 2014; Lakdawalla and Philipson, 2009; Lakdawalla *et al.*, 2005; Philipson and Posner, 2003), unemployment (Latif, 2014; Ruhm, 2000; Triaca *et al.*, 2020), and economic freedom (Lawson *et al.*, 2016; Ljungvall, 2013).

Given the premise of income convergence between countries, a few researchers have focused on the analysis of cross-country disparities in adult obesity. They

examined the convergence in adult obesity for a group of high-income countries using an idea from neoclassical literature on empirical growth. In this context, Li and Wang (2016) were the first to apply convergence analysis to the study of adult obesity prevalence. In their study, Li and Wang (2016) have examined whether adult obesity rates are converging in absolute terms among the 50 states of the U.S. over the period from 1996 to 2001. Their findings have shown evidence of absolute β -convergence in adult obesity rates both during the period 1996-2001 and during several sub-periods. Their findings have further shown evidence of σ -convergence in the sample period.

In another study, Nghiem *et al.* (2018) examined the hypothesis of club convergence in BMI growth rates and the determinants of BMI growth across 34 OECD countries for the period 1980-2008. By using a dynamic methodology suggested by Phillips and Sul (2007), they have found that there is no overall convergence in mean BMI growth rates among OECD countries for both males and females, but there are several convergence clubs. In this regard, their results have shown that there are five groups of countries converged for male BMI growth rates and seven groups for females. Lastly, their results from the regression trees have indicated that income per capita, the ratio of urban populations, the level of carbon dioxide (CO₂) emissions, and excessive consumption of sugar, fat, and alcohol are among the key drivers of BMI growth among OECD countries.

On the other hand, Duncan and Toledo (2018a) have analyzed the hypothesis of obesity convergence among European adults by deriving a testable obesity equation. In other words, in their research, they have first developed a rational, non-addiction eating model, which is widely used in health economics research. Then, they investigated the convergence in mean BMI by gender across 172 countries, which are further divided into two groups: European and non-European countries. Their empirical findings have indicated that both female and male BMIs absolutely converged among 45 European countries over the period between 1975 and 2014. However, for non-European countries, there is no evidence of absolute convergence in mean BMIs. In their study, they further analyzed conditional convergence in BMI for the same sample, conditional upon real GDP per capita, human capital index, and urbanization. However, their findings have shown that although there is evidence of convergence in the BMIs of European countries, the control variables, including per

capita income, human capital, and urbanization rate, do not explain the growth in BMI for both European males and females. In another study, Duncan and Toledo (2018b) empirically examined the absolute convergence in female and male obesity rates for 172 countries over the period 1975-2016. Their findings show that while female and male overweight rates converge in Europe, there is no evidence of absolute convergence among non-European or world countries. They have further shown that their findings on convergence in obesity rates for both genders are robust to the inclusion of several control variables, including the globalization index, real GDP per capita, urbanization rate, and human capital index.

More recently, Alexiadis *et al.* (2019) have investigated spatial convergence in obesity among the 49 states of the U.S. by giving particular attention to the nexus between unemployment and the percentage of obese individuals in the adult population. Their results based on the difference GMM estimator support the hypothesis of obesity convergence over the sample period between 1995 and 2010. Their results have further shown that the unemployment rate is positively associated with obesity and accelerates the speed of obesity convergence among the sample states. Moreover, Kasman and Kasman (2021) have investigated the evidence of convergence in both obesity rates and adult BMI across 35 OECD countries over the sample period between 1975 and 2016. Their results from traditional cross-sectional tests have shown that there is evidence of absolute β - and σ -convergence both in obesity prevalence rates and in adult BMIs for females and males across 35 OECD members. Moreover, they have applied the dynamic panel methodology of Phillips and Sul (2007) to test the existence of club convergence. Their findings contradict the hypothesis of overall convergence in BMIs for both sexes, male and female, but they do support the evidence of distinct convergence clubs and one divergent group over the sample period.

On the other hand, there are only a limited number of studies in the literature that have empirically examined the impact of obesity on income growth and the convergence process. For instance, Alexiadis and Eleftheriou (2011) have tested whether conditional income convergence occurred in 49 U.S. states between 1997 and 2007, while simultaneously examining the impact of adult obesity on income levels and the process of convergence. By employing conventional OLS and Maximum

Likelihood (ML) estimators, they have found that increases in the percentage of obese adults in the total adult population negatively affect the regional income convergence process. Their findings further confirm the existence of regional income convergence among the 49 states of the U.S. over the period between 1997 and 2007. In another study, Oskonbaeva (2021) analyzed the effect of adult obesity on income growth among 20 transition economies by employing a panel ARDL approach. The results of the study have shown that the link between per capita income growth and BMI follows an inverted U-shaped pattern over the period between 2000 and 2016.

This chapter attempts to test the hypothesis of conditional obesity convergence among 38 OECD countries while simultaneously examining the determinants of the growth of adult obesity using aggregate data. In addition, the chapter further tests the hypothesis of income convergence as in previous chapters while simultaneously analyzing the impact of a health-risk factor for health decay—adult obesity—and its determinants on income growth and the convergence process. In this context, this chapter builds on the related literature in the following ways: First, there have been a number of studies that have examined the determinants of obesity and, particularly, the nexus between obesity and income in the framework of the OKC hypothesis.

However, at the macroeconomic level, there have been only a limited number of studies that have examined cross-country convergence in adult obesity and tested the determinants of obesity growth at the same time. In this sense, previous studies on obesity convergence have either examined the hypothesis of club convergence (Kasman and Kasman, 2021; Nghiem *et al.*, 2018), absolute β -convergence (Kasman and Kasman, 2021; Li and Wang, 2016), conditional β -convergence (Duncan and Toledo, 2018a, 2018b), or spatial convergence (Alexiadis *et al.*, 2019) among OECD or EU members. Second, the studies that have tested β -convergence have employed traditional cross-sectional tests for convergence testing, which mainly suffer from omitted variable bias and endogeneity. Third, the studies of Duncan and Toledo (2018a, 2018b) that examined conditional obesity convergence have only included a subsample of OECD members, namely EU countries.

In summary, compared to previous studies, the study in this chapter significantly contributes to the existing and limited literature by (i) examining both absolute and conditional convergence in obesity growth and its determinants, (ii) using

prevalence rates of adult obesity rather than BMIs, (iii) employing a more efficient dynamic panel data approach, system GMM, (iv) including per capita income, the Gini coefficients, the unemployment rate, and openness to trade into the analyses as additional control variables, which were not considered in previous studies, (v) investigating a high-income country problem by including all 38 OECD members in the analyses, and (vi) using relatively more recent data and a longer time period over the years between 1975 and 2016.

Moreover, the study analyzes the hypothesis of income convergence conditional on the prevalence rates of adult obesity and its determinants. To my best knowledge, there are only two macro-level studies that have analyzed the impact of adult obesity on income growth and the convergence process for the states of the U.S. (Alexiadis and Eleftheriou, 2011) and for transition economies (Oskonbaeva, 2021). Therefore, from a macro perspective, this study further fills the gap in the related literature by examining the effects of adult obesity and its determinants on income growth and the convergence process among 38 OECD member countries over the period between 1975 and 2016. Additionally, deviating from previous studies, the study adopts a different methodology, system GMM, which has superior features in terms of both econometrics and growth empirics compared to other traditional OLS and ARDL approaches.

3.3. EMPIRICAL MODEL

The main aim of this chapter is to test convergence in adult obesity prevalence while simultaneously examining the economic determinants of obesity growth. Following the related literature, the research in the study is founded on the claim that weight gain occurs due to poor economic conditions in addition to other genetic and medical factors. In other words, the study argues that the observed trends in excessive weight gain among adults, and therefore in adult obesity prevalence, can be significantly explained by economic factors to an extent that should not be ignored among other non-economic drivers, including genetics, health conditions, and medications. To this end, first, the study asks whether there is a significant relationship between real per capita income and the growth rate of obesity prevalence. Previous

studies in the related literature have argued that per capita income appears to be one of the primary factors that seriously leads to increases in obesity. In other words, several studies have claimed that as income rises, rational individuals devote a greater proportion of their income to consumption of various goods and services that enter their felicity function, one of which includes food consumption. Hence, particularly in a high-income context, as income rises, individuals can afford excess food with this increasing income. As a result, weight gain occurs as income continues to rise.

Therefore, first, the study includes the per capita income levels of the countries to investigate their impact on the growth rate of obesity prevalence. On the other hand, unemployment can be regarded as another key driver of the increases in adult obesity, especially by leading to significant changes in the level of per capita income. In fact, based on Grossman's (1972a, 1972b) model of the demand for health, there exist two competing and opposite arguments that explain the effects of unemployment on obesity. The first argues that unemployment may lead individuals to a non-nutritious, high-calorie, and low-cost diet due to the loss in income, which in turn induces excessive weight gain. However, the second suggests that unemployment decreases the opportunity cost of time to spend on improving health, such as through physical exercise, producing homemade meals, and using preventive health services. Therefore, an increase in unemployment can also lead to a decrease in weight gain.

As a result, although the effects of unemployment on weight gain and obesity have been extensively documented in the related literature, the evidence is still inconclusive given these two conflicting views above. In this sense, several studies in the related literature have shown that unemployment negatively relates to obesity (Ruhm, 2000, 2005; Triaca *et al.*, 2020), while others have reported positive effects of unemployment on obesity levels (Charles and DeCicca, 2008; Latif, 2014; Marcus, 2014). In addition, several studies have further argued that unemployment is associated with high stress and depression (Bradford and Lastrapes, 2014; Tefft, 2012; Zimmerman and Katon, 2005), and the evidence shows that depression leads to significant weight gain due to comfort eating (Dallman *et al.*, 2003; Foss and Dyrstad, 2011; Tomiyama, 2019). To sum up, theoretically, it is difficult to anticipate the effect of unemployment on weight gain, and empirically, its effect significantly varies among studies depending on the sample and methodology used.

Furthermore, by affecting the distribution of income across a country's population, income inequality plays a significant role in the rising trends of adult obesity. In this context, one can argue that higher income inequality creates increased nutritional problems by directing individuals with poor economic status toward a diet that provides maximum calories at the least cost, which in turn increases food insecurity. According to the Food and Agriculture Organization (FAO) (2019), food insecurity is among the key predictors of weight gain and obesity, especially in high-income countries (FAO, 2019: 42). Moreover, income inequality has some psychosocial effects in addition to its economic effects that can influence all other pathways to higher weight gain, including sedentarism, calorie intake, food choice, and stress (Pickett *et al.*, 2005; Wilkinson and Pickett, 2006). Therefore, the study further employs an indicator of income inequality, the Gini coefficients, to test their effects on the growth of obesity prevalence and on obesity convergence.

In order to follow standard practices in the relevant research, openness to trade is also taken into account in the analyses as another factor influencing the prevalence of adult obesity. In the linked literature, there has also been much debate on the effects of trade openness on obesity.¹⁰⁸ In this regard, some researchers have found that openness to trade positively relates to obesity through increasing the promotion and availability of processed foods at lower prices and hence leading to an overabundance of obesogenic foods in the countries' food systems (Clark *et al.*, 2012; Miljkovic *et al.*, 2015; Stuckler *et al.*, 2012). On the other hand, others have found that a higher share of trade in GDP and economic globalization have negative effects on weight gain and obesity rates (Boysen *et al.*, 2019; De Soysa and De Soysa, 2018; Fox *et al.*, 2019; Goryakin *et al.*, 2015). These studies have argued that trade openness has a positive impact on population health due to easy access to different kinds of medical supplies and good health practices, the spillover of medical knowledge, and the increases in income resulting from rising productivity levels. In brief, there is no convincing evidence showing the exact effect of trade on weight gain and obesity.

¹⁰⁸ Please see García-Dorado *et al.* (2019) for a detailed literature review on the effects of trade openness and economic globalization on obesity.

Overall, to address the aforementioned problems and test the obesity convergence hypothesis, this study formulates the factors that contribute to obesity growth as follows:

Model 1:

$$GOBES = f(L.OBES, RGDP, UN, INEQ, OPEN) \quad (116)$$

In Eq. (116), the growth rate of obesity prevalence among adults (*GOBES*) is formulated as a function of the following factors. *L.OBES* stands for showing the initial rate of obesity prevalence and is included in the analyses to control transitional dynamics. *RGDP* denotes real GDP per capita, *UN* shows the total unemployment rate, *INEQ* indicates income inequality, and *OPEN* means openness to trade.

This study further attempts to investigate the impact of obesity prevalence on long-run income growth and the convergence process in order to investigate the nexus between weight-related health and growth and also to preserve the integrity of the thesis. Therefore, in Eq. (117), the study further formulates per capita income growth (*GRGDP*) as a function of the traditional determinants of income growth, including the initial level of per capita income (*L.RGDP*), the investment rate of physical capital (*INV*), and the augmented rate of population growth (*APOPG*). Additionally, Model 2 further includes the prevalence rate of adult obesity (*OBES*) and its determinants, such as the total unemployment rate (*UN*), income inequality (*INEQ*), and trade openness (*OPEN*), which serve as additional control variables for income growth and its convergence process. Lastly, Eq. (117) further includes human capital in the form of education (*HC*) as an additional control variable to partly eliminate the omitted variable problem in growth estimations.

Model 2:

$$GRGDP = f(L.RGDP, INV, APOPG, OBES, UN, INEQ, OPEN, HC) \quad (117)$$

3.4. METHODOLOGY, DATA, AND EMPIRICAL FINDINGS

Eqs. (116) and (117) are transformed to the following dynamic panel data models to investigate the relationship between weight-related health and income:

Model 1:

$$\ln(OBES_{it}) - \ln(OBES_{i,t-1}) = \gamma_1 \ln(OBES_{i,t-1}) + \gamma_2 \ln(RGDP_{it}) + \gamma_3 \ln(UN_{it}) + \gamma_4 \ln(INEQ_{it}) + \gamma_5 \ln(OPEN_{it}) + \varphi_i + \zeta_t + v_{it} \quad (118)$$

Eq. (118) considers Model 1, which was first given in Eq. (116) and is estimated to examine the determinants of obesity growth and the convergence in adult obesity prevalence. In this sense, in Eq. (118), the dependent variable is the log difference in adult obesity prevalence in both sexes over some τ -year period. γ_1 is the coefficient of the log of adult obesity prevalence over the previous τ -year span and it is theoretically expected to be negative to be consistent with the obesity convergence idea.¹⁰⁹ In other words, a lower γ_1 (higher γ_1 in absolute value) indicates the presence of faster obesity convergence. γ_2 is the coefficient of real per capita income and is expected to be positive. That is, increases in per capita income stimulate excessive food consumption and lead to increases in the growth rate of obesity prevalence, particularly in high-income countries. γ_3 shows the effects of the total unemployment rate on obesity growth. The coefficient γ_4 measures the contribution of income inequality to obesity growth and is expected to be negative, *i.e.*, more inequality leads to more weight gain. The coefficient γ_5 shows the effect of trade openness on obesity growth.

For the coefficients γ_3 and γ_5 , which respectively show the coefficients of the total unemployment rate and trade openness, one may not suggest an expected sign as the related literature on their effects on obesity given above is highly diverse. Furthermore, φ_i and ζ_t measure country- and time-specific omitted factors, respectively. Lastly, v_{it} refers to the error component, i indicates cross-sectional units,

¹⁰⁹ Since this chapter does not use a theory-backed convergence equation, the theoretical definition of γ_1 is unknown in this study. Therefore, the estimated rate of convergence cannot be explicitly calculated in the analyses. Please refer to Chapter 1 and Chapter 2 of this thesis for the calculation of the implied convergence rate by using γ_1 and for its detailed theoretical definition.

and t denotes time points. In the estimations, the study first tests the hypothesis of absolute obesity convergence and then adds each determinant of obesity to the analyses one by one. It is expected that the inclusion of the economic determinants of obesity in the estimations will raise the speed of conditional obesity convergence (raise the value of γ_1 in absolute terms) compared to the speed of absolute obesity convergence.

Model 2:

$$\ln(RGDP_{it}) - \ln(RGDP_{i,t-1}) = \gamma_1 \ln(RGDP_{i,t-1}) + \gamma_2 \ln(INV_{it}) + \gamma_3 \ln(APOPG_{it}) + \gamma_4 \ln(OBES_{it}) + \theta \ln(X_{it}) + \varphi_i + \zeta_t + v_{it} \quad (119)$$

Eq. (119) deals with Model 2, given in Eq. (117), which is formulated to examine the effects of obesity prevalence on income growth and the convergence process. In this case, in Eq. (119), the dependent variable is the log difference of real income per capita over some τ -year period. γ_1 is the coefficient of the log of real per capita income in some previous τ -year span and it is theoretically expected to be negative in order to be consistent with the idea of income convergence. Similarly, a lower γ_1 (higher γ_1 in absolute value) indicates the presence of faster income convergence. γ_2 is the coefficient of the investment rate for the physical capital and is expected to be positive. γ_3 shows the effects of the augmented rate of population growth on income growth. The coefficient γ_4 measures the contribution of obesity prevalence to per capita income growth and its convergence process. It is expected that increases in obesity prevalence will slow income growth by increasing absenteeism and presenteeism, which lower labor productivity. It is also expected that the inclusion of the obesity indicator in the analyses will slow the rate of income convergence (a lower γ_1 in absolute value).

θ represents the coefficients of the control variables and X_{it} is the vector of control variables. Control variables include the determinants of obesity prevalence, such as the total unemployment rate (UN_{it}), income inequality ($INEQ_{it}$), and trade openness ($OPEN_{it}$), as well as human capital in the form of education (HC_{it}). These control variables all relate to both obesity and income growth in a country and are included in the analyses to eliminate any omitted variable bias encountered in the estimations. Furthermore, φ_i measures country-specific omitted factors and ζ_t gives

the impact of common macroeconomic shocks on income growth in all sample countries. In other words, empirical estimations assume identical but not constant technological progress across sample countries. Lastly, v_{it} is the usual error component of the regression, i indicates cross-sectional units, and t denotes time points.

3.4.1. Methodology

Eqs. (118) and (119) (Model 1 and Model 2) are estimated by using a dynamic panel data estimator, the system GMM, due to its superior features in terms of growth and convergence empirics. Briefly, this estimator allows for less restrictive assumptions from an economic standpoint while providing more reliable estimates with its superior finite sample properties from an econometric perspective. The estimator enables the inclusion of both individual and period fixed effects in a regression equation and hence allows for consideration of differences across countries and time periods. Therefore, it helps eliminate a few major shortcomings faced by cross-sectional and static panel estimators, including parameter constancy, unobserved heterogeneity, and also endogeneity. It also offers a distinct advantage over other dynamic panel data estimators for obtaining more efficient estimates by (i) allowing the inclusion of more instruments, (ii) improving precision, especially for short panels, and (iii) reducing bias for finite samples, particularly in cases where the sample series are close to being random walks (Blundell and Bond, 2000; Roodman, 2009a).

Moreover, this estimator easily deals with any endogeneity problem originating from both omitted variable bias and the simultaneity that exists between the dependent variable and its determinants. In the case in Eq. (118), not only do increases in income stimulate weight gain, but higher obesity may also reduce income growth by lowering the productivity of the labor force and decreasing the health capital of the population. Therefore, the existence of a strong and robust relationship between obesity and real income that has been documented in the literature—in addition to those between obesity and other control variables—is one of the main reasons to use the system GMM

estimator in the estimations.¹¹⁰ Similarly, as for the case in Eq. (119), it is certain that some of the Solow growth variables are actually determined simultaneously with the level of income, which in turn leads to the problem of dynamic endogeneity. Moreover, this dynamic feedback mechanism may originate due to a possible interrelationship between previous shocks and their current effects on regression variables. In this sense, the system GMM estimator helps deal with any endogeneity issues encountered in the estimation process by instrumenting all endogenous variables with other variables that are regarded as unrelated with unobserved effects. As a result, to avoid any unreliable results that could result from a major unit root problem, the study first examines the time-series properties of the series. Then, it employs the system GMM estimator to test the argument of convergence in both obesity and income.¹¹¹

3.4.2. Data

This chapter uses panel data from 38 OECD countries to test the relationship between weight-related health and per capita income growth over the period between 1975-2016.¹¹² Two different empirical models are estimated in the study: (i) to examine the determinants of obesity prevalence and test the obesity convergence hypothesis, and (ii) to examine the effects of obesity on income growth and test the income convergence hypothesis. To this end, the prevalence rates of adult obesity ($OBES_{it}$) in both sexes are used in the study as a proxy for weight-related health. The data on the prevalence of obesity among adults (age-standardized estimate, %) were obtained from the GHO database of the WHO. The indicator is calculated as the percentage of a sample adult population in both sexes with a BMI of 30 kg/m² or higher (WHO, 2022a). Furthermore, the study uses real GDP per capita ($RGDP_{it}$) to measure

¹¹⁰ A few studies have further argued that there may exist a causal relationship between obesity and economic growth (Go *et al.*, 2021; Kelly *et al.*, 2019); between obesity and productivity (Mazhar and Rehman, 2022); and between obesity and other economic factors (Cawley, 2015; Egger, 2011; Halicioglu, 2013).

¹¹¹ For a comprehensive explanation of the system GMM approach and PURTs applied in the study, please see Section 1.4.1 of Chapter 1.

¹¹² The sample countries are Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

the level and growth of per capita income in OECD countries. The study also includes the total unemployment rate (UN_{it}), Gini coefficients as a proxy for income inequality ($INEQ_{it}$), and openness to trade ($OPEN_{it}$) in the analyses to examine their effects on both obesity and income growth. The data on real GDP per capita (in millions of 2015 US dollars), total unemployment rate (% of total labor force, national estimate), and trade openness (as a percentage of GDP, %) were obtained from the WDI of the WB. Gini coefficients (% equal-split adults), whose higher values correspond to greater income inequality among adults, were obtained from the World Inequality Database (WID, 2022).

For income growth regressions, the study further includes the investment rate of physical capital, the population growth rate, the depreciation rate, and the human capital index in the analyses. The income growth rate is calculated as the logarithmic difference of real GDP per capita ($RGDP_{it}$) between two non-overlapping periods. The investment rate for physical capital (INV_{it}) is measured as the rate of gross capital formation at current PPPs. The annual growth rate of the population ($POPG_{it}$) is calculated from the data on the population (in millions) for each country. The study further allows the depreciation rate of physical capital ($DEPRATE_{it}$) to vary across countries and time instead of assuming a constant rate of three percent. Therefore, the augmented rate of population growth ($APOPG_{it}$) is obtained as the sum of the population growth rate, the average depreciation rate of the capital stock, and the rate of technological progress that is assumed to be constant at 0.02 as in Mankiw *et al.* (1992). The analyses further include human capital in the form of education (HC_{it}) as an additional control variable. The data on human capital is measured as an index that includes schooling years and returns to education. The series for the investment rate, the number of populations, the depreciation rate, and the human capital index were drawn from the PWT version 10.0 (Feenstra *et al.*, 2015).

Table 18: Descriptive Statistics

	<i>Mean</i>	<i>Median</i>	<i>Std. Dev.</i>	<i>Min.</i>	<i>Max.</i>
$OBES_{it}$ (%)	15.42	15.45	6.12	0.60	36.20
$RGDP_{it}$ (in millions, 2015 US\$)	28147.31	26130.86	19289.30	2758.45	112417.90
UN_{it} (%)	7.67	7.06	4.22	0.20	27.47
$INEQ_{it}$ (%)	47.06	45.00	9.84	20.80	73.61
$OPEN_{it}$ (%)	75.42	63.99	45.51	9.10	351.13
INV_{it} (%)	25.87	25.65	6.23	8.16	54.87

<i>POPG_{it} (%)</i>	0.70	0.57	0.80	-2.15	3.72
<i>DEPRATE_{it} (%)</i>	3.64	3.59	0.65	2.07	5.95
<i>HC_{it} (index)</i>	2.95	3.02	0.48	1.36	3.77

Note: Std. Dev., Min., and Max. refer to the standard deviation, the minimum, and the maximum, respectively.

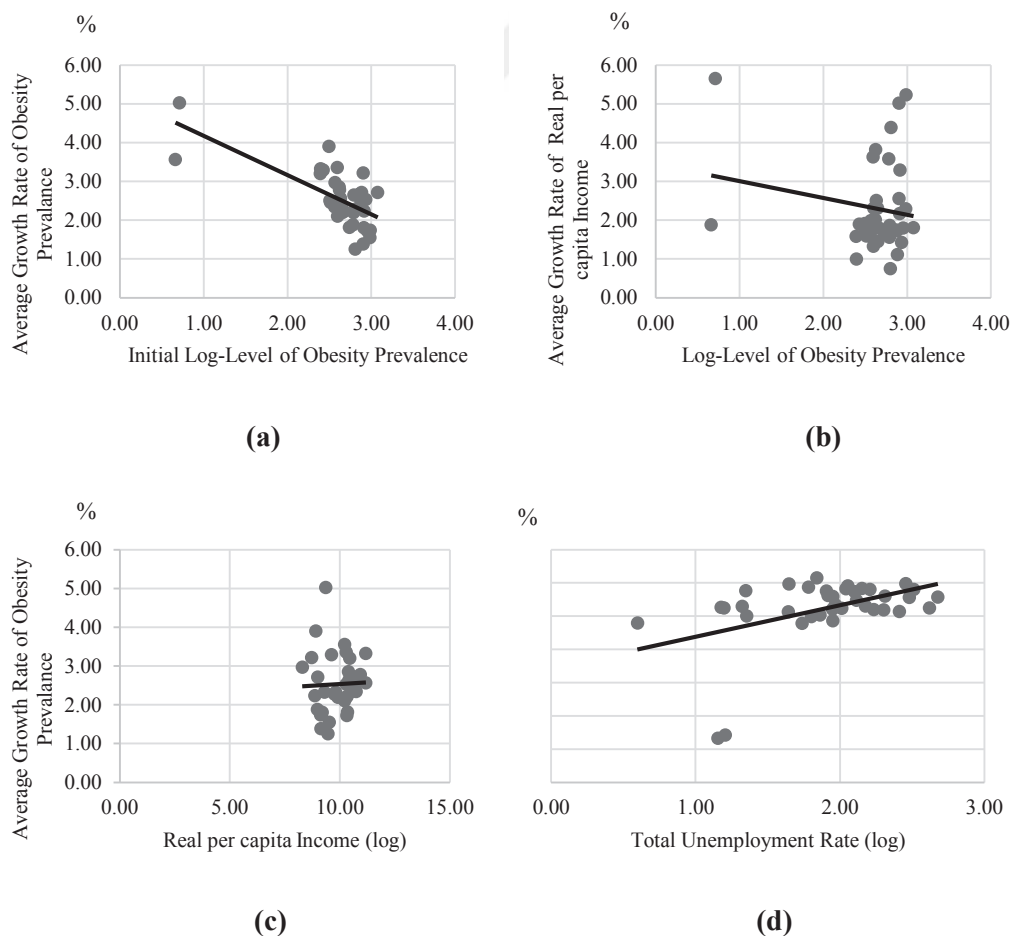
Table 18 presents the descriptive statistics of the annual data for 38 OECD members over the years between 1975 and 2016. Some salient features of the data are as follows: The average prevalence rate of adult obesity in both sexes was about 15.42% in OECD member countries over the period 1975-2016. Among the 38 members, the lowest rate of adult obesity was observed in Korea, with a rate of 0.60 over three consecutive years between 1975 and 1977. On the other hand, the highest rate of 36.20% belonged to the U.S. for the year 2016. Regarding the income levels, most OECD member countries are classified as high-income countries as of 2022, while Colombia, Costa Rica, Mexico, and Turkey are all classified as upper-middle-income countries according to the WB's country classification by income level.

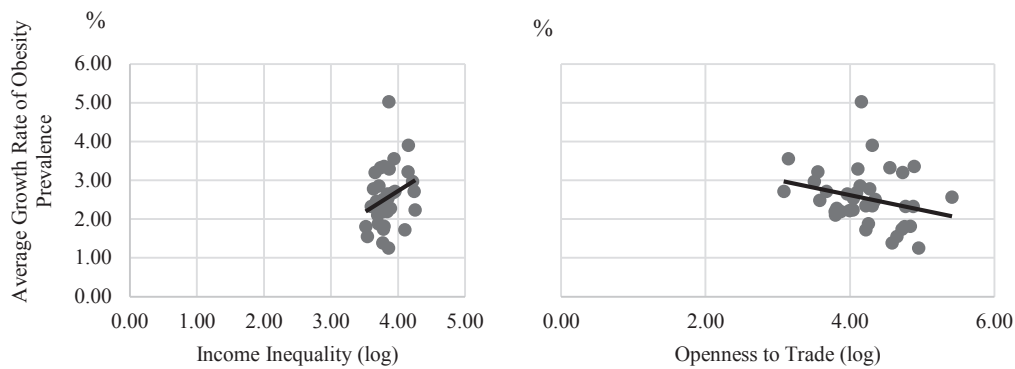
As for unemployment rates, the average rate among 38 members was 7.67% over the period between 1975 and 2016. Over the same period, Switzerland had the lowest rate with about 0.20% in 1980 and 1981, whereas Greece had the highest rate of 27.47% in 2013 due to the serious adverse impacts of the economic crisis experienced in the country. In terms of income inequality, member countries had a relatively higher average rate of about 47.06% than expected, implying that the distribution of income across the OECD population was slightly distorted against low-income individuals over the sample period. Furthermore, over the 42-year period, Gini coefficients ranged from 20.80% in Hungary in 1984 to 73.61% in Chile in 2011. Finally, for trade openness, Luxembourg had the highest openness with a ratio of around 351.13% in 2015, while Turkey had the lowest trade openness with a ratio of about 9.10% in 1979 among the 38 OECD countries.

Figure 8 below plots the relationships between the growth rate of obesity prevalence, income growth, and the determinants of obesity for 38 OECD members over the period between 1975 and 2016. In part (a), the vertical axis shows the average percentage growth rate of obesity prevalence over the period between 1975 and 2016, while the horizontal axis gives the initial log level of obesity prevalence. The graph in part (a) indicates that there is a catch-up process in the prevalence rates of adult obesity

among 38 OECD member countries, except for Japan and Korea. On the other hand, in part (b), the vertical axis measures the average percentage growth rate of real per capita income, and the horizontal axis shows the average log level of obesity prevalence. Part (b) demonstrates that there is a negative relationship between per capita income growth and adult obesity prevalence. Moreover, parts from (c) to (f) show the average percentage growth rate of obesity prevalence on the vertical axis and the log levels of the determinants of obesity on the horizontal axis. According to the graphs, there is a positive correlation between obesity growth and per capita income, the unemployment rate, and income inequality, but this positive correlation seems to be weak if per capita income is considered in part (c). Lastly, part (f) indicates that there is a negative relationship between the growth rate of adult obesity and openness to trade.

Figure 8: Scatter Plots of Obesity Prevalence, Income Growth, and the Determinants of Obesity





(e)

(f)

Source: The calculations of the author. The raw data were from the GHO of the WHO (2022a) and the WDI of the WB (2022).

Once and for all, the study opts for non-overlapping time intervals widely used in the empirical convergence literature to minimize business cycle effects. Therefore, once again, the data used in this chapter were averaged by using non-overlapping 5-year time intervals, as in conventional convergence studies of Islam (1995), Caselli *et al.* (1996), and Bond *et al.* (2001), among others. Hence, the final sample included in the estimations contains 38 OECD member countries and a total of 9 time points observed quinquennially over the period 1975-2016. All variables are used in their natural log forms in the analyses. Hence, each estimated coefficient provides the elasticity of obesity or income growth with respect to related independent variables used in the estimations.

3.4.3. Empirical Findings

Four panel unit root tests are employed to identify the stationarity properties of the annual series in the sample. In other words, three first-generation tests proposed by MW (1999), LLC (2002), and IPS (2003), as well as a second-generation test suggested by Pesaran (2007), are applied in the study to obtain more precise results. The choice of each test depends on the relative sizes of the panel and the time dimension of the sample.¹¹³ In this sense, panels A and B of Table 19 report the results

¹¹³ That is, in the study, the number of panels is equal to $N = 38$ and the size of the time dimension is $T = 42$.

of four PURTs for the natural logarithms and for the first differences in the logs of the annual series, respectively.

Table 19: Results of PURTs

	<i>FISHER ADF</i>	<i>LLC Adjusted t*</i>	<i>IPS W-t-stat.</i>	<i>PESARAN CIPS</i>
PANEL A				
LOG LEVELS				
$\ln(OBES_{it}) - \ln(OBES_{it-1})$	512.026***	-15.229***	-17.563***	-3.169***
$\ln(OBES_{it-1})$	119.787***	-2.785***	1.714	-2.439
$\ln(OBES_{it})$	125.484***	-3.454***	1.660	-2.440
$\ln(RGDP_{it}) - \ln(RGDP_{it-1})$	378.151***	-16.117***	-15.593***	-2.869***
$\ln(RGDP_{it-1})$	64.584	-6.177***	1.427	-2.576*
$\ln(RGDP_{it})$	48.691	3.218	3.168	-2.489*
$\ln(UN_{it})$	134.168***	-0.607	-4.135***	-2.249*
$\ln(INEQ_{it})$	98.997**	-3.010***	-0.528	-2.622*
$\ln(OPEN_{it})$	120.264***	-2.863***	-3.626***	-2.358*
$\ln(INV_{it})$	138.146***	-0.149	-4.290***	-2.041*
$\ln(APOPG_{it})$	562.995***	-17.271***	-21.194***	-2.222*
$\ln(HC_{it})$	87.420	-3.717***	0.961	-5.354***
PANEL B				
FIRST DIFFERENCES IN LOGS				
$\ln(OBES_{it}) - \ln(OBES_{it-1})$	1346.200***	-16.866***	-32.970***	-7.136***
$\ln(OBES_{it-1})$	398.299***	-3.268***	-10.365***	-3.209***
$\ln(OBES_{it})$	622.354***	-7.996***	-12.508***	-3.360***
$\ln(RGDP_{it}) - \ln(RGDP_{it-1})$	594.326***	-15.155***	-22.481***	-3.433***
$\ln(RGDP_{it-1})$	350.124***	-14.978***	-14.458***	-2.528*
$\ln(RGDP_{it})$	361.812***	-14.702***	-14.946***	-2.181*
$\ln(UN_{it})$	354.847***	-11.851***	-14.622***	-2.714**
$\ln(INEQ_{it})$	484.445***	-12.704***	-18.160***	-4.837***
$\ln(OPEN_{it})$	531.860***	-21.707***	-21.358***	-3.338***
$\ln(INV_{it})$	551.298***	-19.992***	-21.840***	-3.790***
$\ln(APOPG_{it})$	763.021***	-21.370***	-24.509***	-4.024***
$\ln(HC_{it})$	87.656	0.626	-0.945	-3.265***

Notes: For each test, the null hypothesis tests the existence of unit root. An intercept and a linear time trend are included in each test for each series. AIC is used to determine the optimal lag lengths. ***, **, and * refer to significance levels of 1%, 5%, and 10%, respectively.

If the results of four tests are considered together, the test statistics for the log levels of the series given in Panel A show that each sample series does not suffer from serious unit root issues. The results of PURTs further show that only the series on the log level of real GDP per capita are described by non-stationary processes according to the results of the first-generation PURTs. However, the results of the CIPS test statistic indicate that the series on the log level of real GDP are also free from the unit

root if the existence of cross-sectional dependence is considered.¹¹⁴ Moreover, for the first differences of the log series, the test results show that all series are defined by stationary processes, except for the index of human capital. The results of the tests indicate that the series on the human capital index seriously suffers from unit root, according to the results of the first-generation tests. However, if one considers cross-sectional dependence, which is highly expected in the case of the OECD, then the null hypothesis of unit root is also rejected for the series of the human capital index.¹¹⁵

The results of system GMM estimations are reported in Tables 20 and 21. Table 20 shows the findings from the estimation of Model 1, which examines the determinants of the growth rate of obesity prevalence and also the convergence in obesity prevalence among OECD members. Therefore, in Table 20, the LHS variable is the change in the logarithm of the obesity prevalence rate in each regression. The lagged log-level of obesity prevalence is treated as predetermined, and all independent variables are considered endogenous. In other words, all independent variables are assumed to be correlated with the shocks to the obesity prevalence both in the current and in the previous periods (*i.e.*, in five-year periods). On the other hand, Table 21 shows the findings from the estimation of Model 2, which examines the determinants of income growth and the effects of obesity prevalence on long-run income growth and the income convergence process among OECD members.

Therefore, in Table 21, the LHS variable is the change in the logarithm of real per capita GDP. Similarly, the lagged log-level of real per capita GDP is treated as predetermined, and all independent variables are considered endogenous due to possible correlations that exist between the independent variables and the current and past shocks to income growth. Moreover, in the growth regressions of Table 21, the augmented rate of population growth is also treated as potentially endogenous following Cho (1996) and Bond *et al.* (2001), given the argument of previous studies that changes in income significantly affect fertility rates, mortality rates, and hence the

¹¹⁴ As discussed in Chapter 1, the system GMM estimator greatly improves the precision even when the series in the panel are highly persistent (Blundell and Bond, 2000; Bond, 2002; Bond *et al.*, 2001).

¹¹⁵ Furthermore, to test for the presence of CD, the Breusch-Pagan (1980) LM test, the Pesaran (2004, 2021) CD and scaled LM tests, and the Baltagi, Feng, and Kao (2012) bias-corrected scaled LM test are implemented in the study. The results show that the null hypothesis of no cross-sectional dependence is rejected in each case. Although the results are not reported to save space, they are available from the author upon request.

rate of population growth (Barro and Becker, 1989; Jones, 1997; Kalemli-Ozcan, 2003; Prettnner, 2013).

In Tables 20 and 21, all regressions include time dummies to prevent possible evidence of simultaneous correlation since the GMM estimators assume that the disturbances are uncorrelated across individuals (Roodman, 2009a). Furthermore, in both tables, each model is estimated using a one-step GMM estimator, following the studies of Blundell *et al.* (2001), Hoeffler (2002), and Ding and Knight (2009), among others. The one-step GMM estimator is always more reliable for finite-sample inference, even in cases of non-normality and heteroskedasticity (Blundell and Bond, 1998: 142). Moreover, the efficiency gains from using a one-step estimator are larger for system GMM than a two-step estimator, and the approximations on familiar asymptotic distributions are more precise for a one-step estimator due to the independence of its weight matrix (Blundell and Bond, 1998, 2000; Bond and Windmeijer, 2002). Therefore, each table presents the findings obtained through the use of one-step GMM estimators.

The bottom parts of Tables 20 and 21 provide the test statistics to check the conditions that verify the consistency of system GMM results. First, the consistency of the estimator depends on the validity of the instrumental variable set. This requires that the instruments and error terms be uncorrelated. This condition is tested by means of the Hansen (1982) test of overidentifying restrictions, which produces the J -statistic to test the null hypothesis that all instruments are valid. Second, the system GMM estimator requires that the extra moment restrictions imposed by Blundell and Bond (1998) be valid. The C -statistic produced by the difference-in-Hansen test is used to test the null of the validity of these subsets of instruments. The p -values of both test statistics given at the bottom part of each table show that the instruments and their subsets are all valid in each estimation.

Third, the existence of the autocorrelation in the disturbance term should be checked to avoid using some lags as invalid instruments. To this end, the z -test proposed by Arellano and Bond (1991) is applied in each regression. In general, the test considers the serial correlation of order $AR(k + 1)$ in the differences to check for the serial correlation of order $AR(k)$ in levels. Hence, the test detects the lagged instruments that become invalid through autocorrelation. In fact, there can be negative

first-order serial correlation in differences, although its existence is not informative. On the other hand, there should be no second- and higher-order autocorrelation (Roodman, 2009a). The test statistics given in the bottom part of Table 20 provide the p -values for Arellano-Bond test statistics for first- ($AR(1)$) and second-order autocorrelation ($AR(2)$). The results in all columns show that there is first-order autocorrelation but no second-order serial correlation in each regression.

However, the test results in Table 21 show that in each case, there is evidence of both first- and second-order autocorrelation, but the regression models do not suffer from third-order correlation ($AR(3)$). Therefore, in each estimation given in Table 21, the instrument set is restricted to lags 4 and longer based on the argument provided by Roodman (2009a). In this sense, he has stated that if the disturbances are serially correlated of order k then, $y_{i,t-(k+1)}$ is endogenous to the k^{th} lag of the disturbance term in the error term in differences and becomes a potentially invalid instrument (Roodman, 2009a: 119). Finally, in each estimation in Tables 20 and 21, the number of groups is greater than or equal to the number of instruments, as required for the consistency of the system GMM estimator to eliminate overfitting endogenous variables (Roodman, 2009a).

Table 20 presents the findings on the determinants of obesity growth and convergence among OECD countries. Column (1) provides the estimation results for the absolute convergence, which is the case when the obesity prevalence rates of a group of economies tend to converge to the same long-run value regardless of any other factor that affects obesity rates. According to the results, the coefficient on the lagged log-level of the obesity rate is significantly negative, indicating that the prevalence rates of obesity among the 38 OECD members converge in an absolute sense over a 42-year period. Moreover, all the other columns of Table 20 deal with the hypothesis on the conditional convergence in obesity prevalence, conditional on real per capita GDP, the unemployment rate, income inequality, and trade openness. In this sense, the findings in column (2) show that the coefficient on the initial rate of obesity is negative and significant. This finding implies the existence of obesity convergence among OECD members, conditional on per capita real GDP. In other words, in line with the findings of previous studies, the results of this study also provide support for per capita real income being one of the key drivers of obesity. The findings in column

(2) show that a 1% increase in real per capita income leads to about a 0.05% increase in the growth rate of obesity prevalence among OECD adults.

Table 20: System GMM Estimations: Determinants of Obesity Prevalence

<i>Dependent variable:</i> $\ln(OBES_{it}) - \ln(OBES_{i,t-1})$	(1)	(2)	(3)	(4)	(5)
$\ln(OBES_{i,t-1})$	-0.084*** (0.022)	-0.129*** (0.030)	-0.124*** (0.026)	-0.126*** (0.025)	-0.116*** (0.028)
$\ln(RGDP_{it})$		0.046* (0.026)	0.030* (0.018)	0.034** (0.016)	0.007 (0.018)
$\ln(UN_{it})$			0.008* (0.004)	0.006* (0.004)	0.000 (0.004)
$\ln(INEQ_{it})$				0.118* (0.064)	0.109** (0.049)
$\ln(OPEN_{it})$					-0.040** (0.017)
<i>Constant</i>	0.321*** (0.070)	-0.020 (0.272)	0.116 (0.205)	-0.367 (0.266)	0.102 (0.228)
<i>AR(1)</i>	0.003	0.034	0.029	0.039	0.035
<i>AR(2)</i>	0.502	0.605	0.520	0.537	0.369
<i>J-stat.</i>	0.157	0.234	0.192	0.174	0.218
<i>C-stat.</i>	0.984	0.131	0.859	0.296	0.710
<i># of instruments</i>	37	14	35	36	33
<i># of groups</i>	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). *J-stat.* and *C-stat.* show the *p*-values for the Hansen and difference-in-Hansen test statistics, respectively. *AR(1)* and *AR(2)* are the *p*-values of the z-test statistics that show serial correlation of order $AR(k + 1)$ in the differences to control for serial correlation of order $AR(k)$ in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

The results in columns (3)–(4) further show that the total unemployment rate significantly and positively affects the growth in obesity prevalence, but the size of its effect is very weak and almost zero in each case. On the other hand, the findings in column (4) indicate that income inequality positively and significantly contributes to the growth in adult obesity prevalence. In this sense, the findings show that a 1% increase in income inequality increases obesity growth by about 0.12%. On the other hand, controlling the effects of trade openness does not change the results regarding the effects of income inequality. In other words, the results in column (5) further show that a 1% increase in income inequality leads to about a 0.11% increase in the growth rate of obesity prevalence among OECD adults. However, the findings in column (5) indicate that the effects of unemployment on obesity growth become insignificant after controlling for openness to trade among OECD members. Similarly, the coefficient on

per capita income is insignificant in column (5) when the regression is simultaneously controlled by income equality and openness to trade. However, the findings show that openness to trade negatively and significantly contributes to the growth in obesity prevalence. In this context, the findings indicate that each one percentage point increase in openness to trade is associated with a 0.04% decrease in the growth rate of obesity among OECD members.

Overall, the findings in each column of Table 20 suggest there has been absolute and faster conditional obesity convergence among OECD members over the period between 1975 and 2016. In this sense, the findings of the study are in line with the findings of Duncan and Toledo (2018a, 2018b), who have found evidence of absolute and conditional obesity convergence among European countries. Increases in income significantly raise the prevalence rate of obesity. This finding is also in line with the extensive literature that has reported income as one of the main drivers of obesity. According to the results of the study, the elasticity of obesity growth with respect to real per capita income ranges between 0.03% and 0.05% in each estimation. The findings further imply that higher unemployment leads to higher weight gain among adults due to a loss in income, but the size of the effect of unemployment on obesity is almost negligible among high-income OECD members compared to other determinants of obesity. This finding supports the findings of Charles and DeCicca (2008), Latif (2014), and Marcus (2014), who have reported positive effects of unemployment on obesity levels, but contradicts the findings of Ruhm (2000, 2005) and Triaca *et al.* (2020).

On the other hand, the impacts of income inequality and trade openness overshadow the effects of other variables, including real per capita income and the total unemployment rate. In this sense, when the estimations are controlled for inequality and openness to trade, the effects of per capita income and unemployment on obesity prevalence become insignificant. The findings in Table 20 further indicate that both trade openness and income inequality are significant and strong determinants of the growth rate of obesity prevalence. In other words, the results show that more openness to trade significantly lowers adult obesity through its health-promoting effects, supporting the arguments of Goryakin *et al.* (2015), De Soysa and De Soysa (2018), and Fox *et al.* (2019). On the other hand, in line with the findings of Pickett *et*

al. (2005) and Windarti *et al.* (2019), higher income inequality leads to higher obesity prevalence among OECD adults, probably through encouraging more food insecurity and sedentary behavior.

Table 21 provides the estimation results for the second model that examines the effects of obesity prevalence on income growth and the convergence process among OECD members. Column (1) shows the estimation results for absolute income convergence, while all other columns (2)–(7) deal with conditional income convergence. According to the results in column (1), the coefficient on the lagged log-level of per capita income is significantly negative, indicating that 38 OECD members converge in an absolute sense over a 42-year period. Column (2) shows the estimation results for income convergence conditional on the traditional determinants of income growth, *i.e.*, the savings rate and the augmented rate of population growth. The results in column (2) show that there is significant evidence of conditional income convergence among OECD members. Furthermore, in line with the findings of the empirical literature on growth, the coefficient of the log-level of initial income is higher in absolute value in column (2) compared to column (1). This finding implies that the speed of conditional convergence is again higher than that of absolute convergence. The findings in column (2) further show that the savings rate has a highly significant and positive effect on income growth. However, the growth effect of the augmented rate of population growth is statistically insignificant.

Column (3) of Table 21 shows the findings when the rate of obesity prevalence is included in the regressions, while all other columns (4)–(7) add other control variables to the regressions one by one in addition to the rate of adult obesity prevalence. In each column (3)–(7), the results show that, although negative, the effects of obesity on income growth are insignificant. This finding may indicate that increases in obesity may have negative but indirect effects on the growth rate of per capita income through other mechanisms such as absenteeism and presenteeism, which may not be well reflected by simple growth regressions as estimated in this study. This result contradicts the findings of Alexiadis and Eleftheriou (2011), who found a significant and negative impact of obesity on income convergence among the 49 states of the U.S. over the period 1997-2007. On the other hand, the findings further indicate that the coefficient on the lagged log-level of the income variable is significantly

negative in each column, showing that there is strong evidence of conditional income convergence among OECD members. However, the inclusion of obesity and other control measures significantly reduces the convergence rate among OECD members compared to those found in column (2), but their inclusion increases the speed of convergence compared to column (1).

Table 21: System GMM Estimations: Growth Effects of Obesity Prevalence

<i>Dependent variable:</i> $\ln(RGDP_{it}) - \ln(RGDP_{it-1})$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln(RGDP_{it-1})$	-0.075*** (0.014)	-0.127*** (0.037)	-0.110*** (0.026)	-0.119*** (0.033)	-0.104*** (0.031)	-0.100*** (0.024)	-0.111*** (0.035)
$\ln(INV_{it})$		0.324*** (0.096)	0.244*** (0.057)	0.296*** (0.060)	0.267*** (0.043)	0.284*** (0.054)	0.226*** (0.043)
$\ln(APOPG_{it})$		0.033 (0.255)	-0.125 (0.111)	-0.265** (0.125)	-0.103 (0.133)	-0.190* (0.102)	-0.060 (0.118)
$\ln(OBES_{it})$			-0.049 (0.063)	-0.019 (0.064)	-0.050 (0.058)	-0.078 (0.066)	-0.051 (0.060)
$\ln(UN_{it})$				-0.088*** (0.033)	-0.020 (0.034)	-0.017 (0.039)	-0.013 (0.030)
$\ln(INEQ_{it})$					-0.080 (0.162)	-0.072 (0.155)	-0.058 (0.246)
$\ln(OPEN_{it})$						-0.039 (0.052)	-0.036 (0.048)
$\ln(HC_{it})$							0.253 (0.235)
<i>Constant</i>	0.819*** (0.147)	0.246 (0.461)	0.782* (0.433)	1.042** (0.499)	0.953 (0.641)	1.243 (0.816)	0.844 (1.107)
<i>AR(1)</i>	0.000	0.003	0.001	0.029	0.005	0.006	0.003
<i>AR(2)</i>	0.029	0.003	0.015	0.006	0.004	0.007	0.008
<i>AR(3)</i>	0.613	0.982	0.755	0.793	0.963	0.976	0.925
<i>J-stat.</i>	0.185	0.112	0.192	0.148	0.147	0.246	0.237
<i>C-stat.</i>	0.580	0.647	0.901	0.223	0.709	0.962	0.570
<i># of instruments</i>	37	26	32	33	32	36	32
<i># of groups</i>	38	38	38	38	38	38	38

Notes: Heteroskedasticity-consistent standard errors are in the parentheses. In each estimation, the instrument sets are collapsed following Roodman (2009b). *J-stat.* and *C-stat.* show the *p*-values for the Hansen and difference-in-Hansen test statistics, respectively. *AR(1)*, *AR(2)*, and *AR(3)* are the *p*-values of the z-test statistics that show serial correlation of order *AR(k + 1)* in the differences to control for serial correlation of order *AR(k)* in levels. The symbol # means the number. The superscripts ***, **, and * denote the significance levels at 1%, 5%, and 10%, respectively.

Moreover, the findings in columns (4)–(7) show that both the total unemployment rate and income inequality have negative but insignificant effects on income growth in OECD countries. Only in column (4) does the coefficient of the unemployment rate become significant and negative, indicating that each one percentage point increase in the total unemployment rate lowers income growth by about 0.09 percentage points in OECD members. This figure is far below that historically suggested by Okun’s Law, although this topic is outside the scope of this study. Furthermore, in all other columns (5)–(7), the effects of unemployment are insignificant. Lastly, the results in columns (6)–(7) further show that both openness to

trade and human capital in the form of education do not significantly explain income growth and the convergence process among OECD members over the years between 1975 and 2016. On the other hand, in each column (3)–(7), the effects of the savings rate are positive and highly significant, but their magnitudes are lower than those found in column (2). However, the effects of population growth are negative but insignificant in most estimations.

3.5. CONCLUDING REMARKS AND POLICY IMPLICATIONS

This chapter contributes to understanding the nexus between weight-related health and income growth for the panel of 38 OECD members over the period 1975–2016. To this end, the prevalence rates of adult obesity in both sexes are used as weight-related health indicators in the study. More particularly, the study relies on an empirical and neoclassical growth framework to explore the nexus between obesity prevalence, income growth, and the determinants of the growth in adult obesity. In this respect, the study first tests the existence of absolute and conditional convergence in adult obesity and additionally investigates the economic determinants of obesity growth among OECD members. In the second step, the study tests the hypotheses of absolute and conditional income convergence, conditional upon adult obesity rates, and the economic determinants of obesity growth. These income growth regressions further include the human capital index as an additional control variable to partly eliminate the omitted variable bias in the analyses. Each regression was run using a robust and dynamic system GMM approach for 38 OECD members from 1975 to 2016.

The main findings of the study show the validity of absolute and faster conditional obesity convergence among OECD countries over a 42-year period. The findings of the study further show that the finding on obesity convergence remains robust to the inclusion of the determinants of obesity in the analyses. In this sense, the results indicate that increases in per capita income significantly raise the growth rate of obesity prevalence among OECD adults. Moreover, the results also show that the total unemployment rate significantly and positively affects obesity growth, implying that unemployed individuals are at greater risk of being obese in OECD members.

However, the results also show that the size of its effect is very weak and almost negligible among high-income OECD members compared to other determinants of obesity. On the other hand, the findings indicate that each one percentage point increase in income inequality leads to about a 0.11%–0.12% increase in the growth rate of adult obesity, probably through encouraging more food insecurity and sedentary behavior. The findings further indicate that openness to trade significantly and negatively relates to the growth in obesity prevalence, indicating that OECD members that are more open to trade have a lower obesity growth rate. In addition, the results further show that the effects of per capita income and unemployment on obesity growth become insignificant when the estimations are controlled for income inequality and openness to trade. This finding may suggest that income inequality and trade openness may better explain the growth in obesity prevalence among OECD adults.

Overall, the results of the study reveal that economic factors significantly explain the observed trends in obesity prevalence to an extent that should not be ignored among other non-economic determinants, including genetics, health conditions, and medications. Furthermore, the chapter's second model investigates the effects of obesity rates and its determinants on income growth and the convergence process among OECD members. According to the results, there is evidence of absolute and faster conditional income convergence among OECD members over the sample period. The results further show that the effects of obesity rates on income growth are negative but insignificant in each regression. This finding may indicate that increases in obesity may have negative but indirect effects on the growth rate of per capita income through other mechanisms such as absenteeism and presenteeism, which may not be well reflected by simple growth regressions as estimated in this study. The findings further indicate that other control variables have no role in explaining income growth and the convergence process among OECD members, except for the savings rate. The effects of the savings rate on income growth are positive and highly significant in each case. Lastly, although insignificant, the inclusion of obesity and other control measures significantly reduces the speed of income convergence among OECD members.

The findings of the study have several policy implications. First, the findings of the study obviously suggest that increases in per capita income levels lead to rising

body weight trends among adult populations in the member countries of the OECD. In this sense, the findings suggest that a strong policy initiative aiming to prevent obesity is especially required for high-income OECD members, such as impeding overconsumption of obesogenic foods, promoting health diets, and encouraging more active living. Second, reducing unemployment will have a somewhat useful role in explaining obesity trends among members. However, as obesity growth is not very sensitive to increases in total unemployment rates, policy-makers may address other determinants of obesity instead of unemployment among OECD members. Third, the findings of the study suggest that serious efforts should be made to reduce income inequality among OECD populations. In this sense, some form of redistributive policy may be helpful for the prevention of unfavorable weight outcomes within the OECD. Finally, more openness to trade leads to lower weight gain through its health-promoting effects in OECD members. Hence, as a policy implication, trade policy strategies encouraging OECD economies to be more open to trade will enable the spillover of medical knowledge, supplies, and good health practices across member countries, which in turn will directly improve the population's weight-related health status among OECD nations.

All in all, obesity remains a challenging public health issue that threatens population health in OECD countries. It has negative impacts on national economies through obesity-related health costs. In particular, as one of the risk factors for developing a NCD, obesity is one of the leading challenges during the COVID-19 pandemic for a number of countries in the OECD group. This study suggests that policies aiming at controlling and preventing rising obesity trends should include public health policies that reduce excessive consumption of obesogenic foods and sedentary lifestyles, macroeconomic policies that support more equal distribution of income, and trade policies that encourage countries to be more open to international trade and enable the diffusion of medical goods, healthy products, and good health and nutrition practices across member states. On the other hand, the findings of the study seriously suggest that future research is required to better understand the impact of obesity on income growth and the convergence process among OECD members in order to assess its economic costs to country economies and counteract the rise in its prevalence.

CONCLUSION

This thesis takes seriously the well-rounded relationship between economic growth and health. In other words, this thesis significantly contributes to understanding the path from health to growth by separately considering the impact of each component of a health capital equation on economic growth. In particular, in Chapter 1, the thesis theoretically and empirically explores the nexus between economic growth and the labor force implications of health by emphasizing the consequences of poor health status at work, *i.e.*, sickness absenteeism. In Chapter 2, the thesis focuses on health care expenditures as a key component of health investments to improve health status by providing a distinction between different financing sources of health care both from a theoretical and empirical point of view. Lastly, in Chapter 3, the thesis highlights the relationship between economic growth and one of the most serious public health issues of recent years, the growth in adult obesity. That is, Chapter 3 empirically investigates the link between income and poor weight-related health status as a risk factor for the high rates of discount in health capital. As a result, the thesis provides three essays, each of which examines one component of the health capital equation in a detailed manner, provides a few novelties, and hence significantly contributes to its related literature.

Chapter 1 investigates the consequences of sickness absenteeism on per-worker output growth and the convergence process in a Solow framework with the government. The theoretical results of the study show that the steady-state values of per-worker variables—including real output, physical capital, and consumption—are all lower than the steady-state values obtained from the solution of the standard Solow model, which assumes that all workers are always healthy and available for work. In other words, higher sickness absenteeism or a decrease in the share of healthy workers reduces per-worker capital formation, output per worker, and consumption per worker in the long run. The results further indicate that all these per-worker variables start to grow at the same constant rate of technological progress at long-run equilibrium, as predicted by the basic Solow model. The theoretical results further show that in the presence of a production externality, increases in the income tax rate reduce capital accumulation and disposable income, depending on the relative magnitudes of the

externality and the income tax rate. However, in the absence of externalities generated by government expenditures, one can easily show the welfare loss in an economy depending on the rate of income taxation. The findings imply that in a closed economy with a balanced budget government, the income tax rate should be chosen to be equal to the elasticity of output with respect to government expenditures in order to optimize long-run per-worker consumption expenditures.

The empirical findings based on system GMM estimates support absolute and faster conditional output convergence among OECD countries, in line with the empirical regularities of economic growth. Furthermore, the empirical findings confirm the theoretical results of the study. In this sense, the findings indicate that decreases in the share of healthy working hours significantly lower capital accumulation and reduce long-run output growth. Vice versa, lower sickness absenteeism boosts long-run output growth through its positive effects on labor productivity. Moreover, the findings of the study show that controlling for the health indicators in the estimations significantly increases the speed of output convergence. Over a 39-year period, the estimated rate of convergence among OECD members is found to be around 6% per year, regardless of whether the regressions include the share of healthy workers or absent days. Furthermore, this rate remains robust despite the inclusion of fiscal policy and control variables. Technically, this finding implies that OECD countries can move halfway to the steady state in about 11 years by increasing the share of healthy working hours or decreasing sickness absenteeism.

The findings of the study also indicate that the good health status of the workforce, as measured by increases in young- and middle-age longevity and decreases in adult mortality between the ages of 15 and 60, has a positive, significant, and sizeable impact on the long-run output growth performance of OECD countries. The positive contribution of life expectancy to growth gradually decreases in magnitude with increasing age. In particular, the findings show that increases in life expectancy at ages 50 and 60 have an insignificant effect on output growth. The findings further indicate that annual gains in young-age longevity significantly increase the speed of convergence, but the estimated convergence rates gradually decrease with rising age after age 20. Parallel to this finding, controlling for young-age longevity between ages 15 and 30 leads to a significant increase in the estimated

output shares of labor, confirming the findings on faster convergence rates, while controlling the longevity of ages 40, 50, and 60 produces relatively higher weights for physical capital. Following that, the findings show that the growth-enhancing effects of the savings rate remarkably increase with increasing age. In other words, increases in the longevity of those between the ages of 50 and 60 increase output growth indirectly through increases in their savings.

The results of Chapter 1 suggest that a country's ability to remain productive vitally depends on the healthiness of its workforce, as the results significantly reveal that workforce health is one of the primary determinants of long-run productivity and output growth. In this sense, policies to boost long-run output growth should promote investments in health, as these investments can be translated into increases in the amount of healthy time available for work through lower rates of absenteeism and increases in the size of the active labor force. The findings of the chapter further suggest that increases in young-age longevity are a significant driver of long-run output growth among OECD countries. Therefore, policy-makers should notice that increasing health investments, providing health care provisions, and promoting healthier lifestyles for the younger workforce will remarkably contribute to long-run output growth and the faster elimination of productivity gaps among OECD countries. Furthermore, the results of the study imply that one of the main objectives of policy-makers to promote economic growth should be to provide an efficient investment environment by means of incentives for the private savings of the elderly workforce, which is notably high among OECD countries due to aging problems.

Lastly, the empirical findings show that higher rates of adult mortality lower long-run growth through the loss of human capital at productive ages and by adversely affecting the incentives to invest in physical capital. Therefore, the findings of the chapter reveal that improvements in the health status of the working-age population—through increases in life expectancy of the younger workforce and decreases in adult mortality—help boost per capita output growth and remarkably reduce the real output differences across OECD members. Furthermore, as a policy implication, the findings also indicate that increases in the size of government expenditures have a significant and negative impact on output growth in OECD countries, which may further indicate the serious burden of government spending among OECD economies, given their

larger budget deficits in recent years and probably the lack of growth-enhancing public spending.

Chapter 2 investigates the nexus between health expenditures and economic growth by highlighting the effects of personal and public health spending on economic growth. The results of all theoretical models imply that technological progress is a crucial driver of both personal and public health expenditures in the long run, as revealed by the related literature. Regarding the results of the Ramsey models, an increase in income leads households to begin consuming more health goods and services again, emphasizing one of the key reasons behind significant increases in health consumption among high-income countries. This increase in consumption leads to an increase in welfare but also raises concerns about household and government budgets due to unsustainable increases in health spending. Furthermore, in the presence of production externalities, the results show that each increase in personal health consumption raises capital accumulation and disposable income through its positive effects on labor productivity but lowers the resources used for non-health consumption, and so to speak, lowers the quality of life for households.

The inclusion of public health spending into the model causes two competing effects depending on the sizes of the income tax rate and production externalities. It leads to a reduction in capital accumulation and disposable income through income taxation. On the other hand, it leads to an increase in capital accumulation and disposable income through its positive effects on labor productivity, which in turn gives households greater access to all the goods and services they consume and thereby increases their welfare. Due to the same reason, the findings show that the destructive effects of income taxation are lessened compared to the case where there are no externalities generated by public health spending. Heuristically speaking, under the gross substitutability between health and non-health consumption, public health expenditures help households establish a more balanced trade-off between quantity and quality of life. Furthermore, in the absence of production externalities, the existence of public health services directly lowers the long-run value of personal health consumption in favor of households and raises the value of non-health consumption. Of course, with or without externalities, this favor of the government cuts down the

resources available for use in other sectors of the economy in which the government is involved, raising concerns about government budgets.

On the other hand, the results of the augmented Solow differently indicate that each increase in the marginal propensity to consume for health negatively affects the long-run savings rate. Of course, if health expenditures are undertaken by the government, then the results show that increases in the share of public health spending in total government expenditures directly raise all the long-run values of the model variables and free the savings rate from the restrictive effects of personal health spending. The model further implies that the income tax rate should be chosen to be equal to the output share of the effective labor force in order to optimize long-run public health expenditures. Following the Solow models, the empirical findings of the chapter are as follows: First, the results of the system GMM estimations provide support for absolute and faster conditional income convergence among OECD members. Second, the findings show that private contributions, including those of households, corporations, and non-profit organizations, positively contribute to long-run income growth in the OECD group. However, given the serious concerns about government budgets caused by rising NCDs and population aging among OECD members, the growth effects of public health spending in OECD countries are ambiguous and call for further research.

Based on the theoretical and empirical findings of this chapter, the policy implications are not straightforward and do not directly impose a private or public option for OECD economies. Nonetheless, one may seriously suggest that policy-makers in these countries should focus on planning the extent to which increased health spending in the future should be financed from personal or public sources, each of which is not cost- and hassle-free. The trade-offs on the budgets of individuals, competing demands for government resources, and the burden of taxes as a main source of public health care financing should be seriously considered in that choice. Furthermore, because these expenditures are critical to increasing total output and individual welfare through their positive effects on labor productivity and are unavoidable in producing health, one policy suggestion may be to increase not the size but the efficiency of the health care sector and its expenditures in OECD countries. Furthermore, raising public awareness for healthier lifestyles and promoting conscious

consumption of health goods and services will be influential in lowering health care costs and increasing the efficiency of the health care sector in high-income OECD members. Otherwise, given that increases in income are among the main drivers of rising health spending, health expenditures may become a risk for the growth and welfare prospects of these countries.

The empirical findings using LDC data indicate evidence of absolute and faster conditional income divergence among LDCs. Furthermore, the findings show that health expenditures from all financing sources, even surprisingly external ones, have a negative effect on long-run economic growth. Moreover, the findings show that only out-of-pocket health expenditures of individuals, which are the primary source of health care financing in most LDCs, positively contribute to income growth and the convergence process among this country group. This means that only individual efforts positively contributed to spending on health and thereby to health production in this country group during the previous 20-year period. Furthermore, among the determinants controlled in the estimations, only the traditional determinant of income growth, the savings rate, has a remarkable and positive effect on the income growth rate of LDCs. Furthermore, its effects are quite strong and high in LDCs, just as they were in OECD members.

Therefore, given the results of the study, one may suggest that for LDCs with relatively poor health and economic status, the problem is to both raise health expenditures and lower the pressures on their budgets at the same time. Increasing spending on health is necessary for LDCs to enhance the health level of the population, to be productive at all, and thereby to boost income growth with the size of the health care sector in contrast to OECD members. However, in these countries, expenditures on health, and thereby health capital, are primarily produced by household consumption. Therefore, for these countries, one policy implication may appear to be raising public backup in health spending to depressurize individual budgets and thereby enhance both the quality and quantity of life for the people in LDCs. Although the empirical findings indicate that public health expenditures have a negative impact on income growth, this finding may arise due to the inefficient use of highly scarce resources in these countries. Therefore, developing a comprehensive national health policy and strategy in these countries and ensuring its effective implementation may

be supportive of raising health spending and exploiting its positive effects on labor productivity, which in turn enhance long-run income growth.

Moreover, the findings of the study further indicate that controlling health expenditures in the analyses does not lead to any significant evidence of convergence among the sample countries in this group. Hence, one may easily argue that it is impossible for these countries to close their gaps with each other and other country groups as long as current practices continue to be implemented. Given the presence of relatively higher savings rates, policy-makers in these countries should primarily foster policies that will support income growth and push convergence by (i) enabling the diffusion of technology among these countries, (ii) directing these relatively higher investments to more appropriate areas that will ensure lower economic vulnerability in these countries, and (iii) directing a portion of these investments as health care investments to promote population health status and thereby enhance human assets and capabilities. Otherwise, the long-run growth prospects for these countries may virtually disappear. Lastly, future research is required to examine the effects and effectiveness of both public and external health expenditures in LDCs.

Finally, Chapter 3 empirically examines the link between weight-related health status, proxied by adult obesity prevalence, and income growth for the panel of 38 OECD members by adopting an *ad hoc* Barro-regression approach. The results from system GMM estimation provide clear evidence of absolute and faster conditional obesity convergence among OECD countries over a 42-year period. The findings of the study further show that the findings on obesity convergence remain robust to the inclusion of the determinants of obesity in the analyses. In this sense, the results indicate that increases in per capita income and in the total unemployment rate significantly raise the growth rate of obesity prevalence among OECD adults, implying that unemployed individuals are at greater risk of being obese in relatively high-income OECD members, through adopting more health-damaging behaviors, *e.g.*, the replacement of a healthy diet. However, the results further show that the size of the effect of unemployment is very weak and almost negligible among OECD members compared to other determinants of obesity. Furthermore, the results also show that the effects of per capita income and unemployment on obesity growth become insignificant when the estimations are controlled for income inequality and openness

to trade. This finding may suggest that income inequality and trade openness may better explain the growth in obesity prevalence among OECD adults.

The results also show that each increase in income inequality leads to significant increases in the growth rate of adult obesity, probably through encouraging more food insecurity and sedentary behavior. Moreover, more openness to trade leads to lower weight gain through its health-promoting effects in OECD members. Overall, the results of the study reveal that economic factors significantly explain the observed trends among other non-economic determinants, including genetics, health conditions, and medications. In this sense, as a policy implication, serious efforts should be made to reduce income inequality among OECD populations, as the results significantly indicate that more unequal societies within the OECD are more vulnerable to being obese. In this sense, some form of redistributive policy may be helpful for the prevention of unfavorable weight outcomes within the OECD. Additionally, trade policy strategies encouraging OECD economies to be more open to trade will enable the spillover of medical knowledge, ease the access to different kinds of medical supplies, and promote good health practices, which in turn will directly improve the population's weight-related health status among OECD nations. Of course, impeding overconsumption of obesogenic foods, promoting healthy diets, and encouraging more active living are also among other policy efforts that are required in OECD members, which are currently struggling with a growing obesity epidemic.

The second model of the chapter aims to understand the impact of adult obesity prevalence and its determinants on income growth and the convergence process among OECD members. According to the results, there is evidence of absolute and faster conditional income convergence among OECD members. However, the results indicate that the effects of obesity rates on income growth are negative but insignificant in each estimation. In addition, all control variables have no role in explaining income growth and the convergence process among OECD members, except for the savings rate. However, although insignificant, the inclusion of obesity and other control measures significantly reduces the speed of conditional income convergence among OECD members. These findings may indicate that increases in obesity may have negative but indirect effects on the growth rate of per capita income through other mechanisms such as absenteeism and presenteeism, which may not be

well reflected by simple growth regressions as estimated in this study. Therefore, the results of the study call for future research to investigate the impact of obesity on income growth and the convergence process among OECD members in order to assess the economic costs of obesity to country economies and counteract its rising prevalence.

All in all, the findings of the thesis show that health status and its components, such as health investments and factors causing a decline in health status, are significantly related to the understanding of countries' economic environments. When all chapters are considered together, this thesis provides detailed and up-to-date findings on the link between health and growth prospects for OECD economies, for which the evidence is still mixed to provide precise policy recommendations and there are still unresolved issues related to health. In the first place, rather than dealing with low longevity and high infant mortality rates, OECD members have recently faced the burden of a growing aging of the workforce (OECD, 2019b, 2020a), low fertility rates that are below those required to assure generational replacement (Sleebos, 2003), increasing NCDs and obesity as one of the major risk factors (Geppert *et al.*, 2019; OECD, 2021), and uncontrollable increases in health care spending (OECD, 2017). On the other hand, the WHO stated that the COVID-19 pandemic continues to negatively affect health systems and the health of populations around the world, even though it has been two years since its first start (WHO, 2022b). As of December 2022, the WHO reported that there have been 639.572.819 confirmed cases of COVID-19 and 6.615.258 deaths globally (WHO, 2022c).

As an unexpected shock, the pandemic caused unprecedented increases in the number of adult deaths, a decrease in life expectancy, and serious working hour losses due to ill health, employment loss, and prolonged symptoms of COVID-19 in OECD countries (ILO-OECD, 2020; OECD, 2021). Given the findings of this thesis, one may expect that the pandemic will try to hinder the long-run growth performance of OECD economies through decreases in the size of the active workforce, in labor productivity due to ill health, and their adverse impacts on the incentives for saving. Therefore, given all the above arguments, the results and subsequent policy suggestions of this thesis accommodate important policy information for this country group to consistently promote health and living conditions and sustain their growth prospects.

Moreover, the OECD (2021) has reported that total health spending sharply increased by 4.7% in 2020 during the COVID-19 pandemic, the highest rise in health care expenditures in OECD members in around 15 years. However, as implied by the results of this thesis, there is always a direct trade-off between the resources allocated to health and non-health uses.

Health care expenditures play a dual role in economies; they are unavoidable in order to maintain and improve good health status, but they are also a significant cost item on budgets. Furthermore, OECD members have already allocated 8.4 percent of their total health budgets to preventing obesity-related diseases (OECD, 2019a). Obesity, in addition to contributing to rising health-care costs, increases the likelihood of developing a severe COVID-19 (Dicker *et al.*, 2020; Frühbeck *et al.*, 2020; Kluge *et al.*, 2020) and has significant negative consequences for population health. It is expected that obesity and related diseases will reduce life expectancy by 0.9–4.2 years over the period 2020-2050 (OECD, 2019a: 21). In this sense, developing a mix of common policies that combine both economic and public health interventions is required for member countries, as suggested by the results of this thesis. These policy efforts may help to lower the enormous rise in the size of the health care sector and prevent health expenditures from becoming a substitute for both the growth and welfare prospects of these countries.

Technically, in terms of growth modeling, the works in this thesis clearly reveal that the canonical Solow model still provides a suitable framework to examine the link between health and economic growth. On the other hand, the Ramsey framework is also intended for examining the effects of health variables on the welfare of individuals and society in addition to long-run growth performance. However, there is a need for future research to better understand and further examine the link between health and economic growth, relying on different assumptions and using different frameworks for growth modeling. In this sense, there is more space in the neoclassical framework to obtain a more complete picture of this link as well as in the framework of endogenous growth models for future research to address this link by simultaneously emphasizing the implications of health capital, health care investments, and human capital. On the other hand, in terms of growth empirics, there may be a need for further econometric approaches to obtain more precise estimates of health and growth variables and fill the

gaps in the evidence. Due to its superior features for empirical growth research, as argued in the first chapter, the system GMM estimator has been employed in each estimation of this thesis. Compared to previous literature, the use of this estimator corrects for finite sample bias, endogeneity, and weak instrument problems and produces robust estimates on growth and convergence.

Testing the relationship between health and growth by means of more recent econometric approaches, such as those considering cross-sectional dependency among country units, will contribute to obtaining new evidence on this subject and therefore be among the future work plans. Moreover, as given in each chapter of the thesis, the empirical findings also call for future research on the effects of human capital and fiscal policy variables on the path from health to growth among OECD countries. In addition, future research should be done on the growth effects of health care spending provided from different financial sources as a key factor in the production of health capital, particularly in LDCs. Furthermore, due to the lack of data on morbidity rates, there is also a need for research to further investigate the nexus between economic growth and diseases and their related risk factors that cause the deterioration of good health status. In this sense, this thesis provides macro-based evidence, but there is a need for micro-based studies to explore and obtain further information on the above issues in detail.

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APPENDIX 1: Derivations of the Extended Solow Model

In a Solovian framework, suppose that the continuous and twice-differentiable C-D production function, $F: \mathbb{R}_+^2 \rightarrow \mathbb{R}$, is defined as follows:

$$Y_t = K_t^\alpha \cdot (T_t \cdot L_{Ht})^{1-\alpha} \quad (\text{A1})$$

where Y_t is the total output, K_t is the physical capital, L_{Ht} is the healthy labor force, T_t is the overall technological progress, and the subindex t represents time. The technological progress T_t and the total labor force L_t are exogenously defined as $T_t = T_0 \cdot e^{\omega t}$ and $L_t = L_0 \cdot e^{nt}$, where ω and $n \geq 0$ represent the exogenous growth rates of the technological progress and the labor force, respectively. α and $1 - \alpha$ represent the elasticity of output with respect to physical capital and labor force (the healthy and effective labor force) and α lies between zero and one, $0 < \alpha < 1$. The total labor force in a country is assumed to be divided into healthy $\phi_H = \frac{L_{Ht}}{L_t}$ and unhealthy labor stocks $\phi_{UH} = (1 - \phi_H) = \frac{L_{UHt}}{L_t}$, i.e., $L_t = \phi_H L_t + (1 - \phi_H) L_t$. Hence, L_{Ht} is some constant share of the total labor stock, which is actively participating in the production process, while L_{UHt} is the stock of an unhealthy labor force, which is not available for production due to their health problems.

The exogenous parameter ϕ_H shows the proportion of healthy workers and is assumed to be $0 < \phi_H < 1$. In this sense, the production function per unit of effective labor is given by $\tilde{y}_t = \tilde{k}_t^\alpha \cdot \phi_H^{1-\alpha}$, where $\tilde{y}_t = \frac{Y_t}{T_t \cdot L_t}$, $\tilde{k}_t = \frac{K_t}{T_t \cdot L_t}$, and $\phi_H = \frac{L_{Ht}}{L_t}$. The model further assumes that a balanced-budget government $G_t = \bar{\tau} \cdot Y_t = TAXR_t$ collects tax revenue ($TAXR_t$) via income tax at a rate of $\bar{\tau}$ to provide goods and services ($0 < \bar{\tau} < 1$). In practice, these general expenditures (G_t) of the government have a positive impact on the entire production process of the firms. Hence, the intensive form of the production function extended with government expenditures is now defined as $\tilde{y}_t = \tilde{k}_t^\alpha \cdot \phi_H^{1-\alpha} \cdot \tilde{g}_t^\vartheta$, where $0 < \vartheta < 1$. In other words, in the presence of a balanced-budget government, the production function per unit of effective labor can be re-expressed as follows:

$$\check{y}_t = \check{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}} \quad (\text{A2})$$

Hence, by using the augmented version of the production function in Eq. (A2), the fundamental equation of growth in effective labor terms can be easily rewritten as¹¹⁶

$$\dot{\check{k}}_t = s_K \cdot (1 - \bar{\tau}) \cdot \check{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}} - (n + \omega + \delta) \cdot \check{k}_t \quad (\text{A3})$$

Eq. (A3) gives the standard capital accumulation equation in effective labor terms, in which $\dot{\check{k}}_t$ is the change in the stock of physical capital per unit of effective labor (or net investments in effective labor terms at time t), s_K is the savings rate of physical capital, and $\delta \geq 0$ is the depreciation rate of physical capital. Note that macroeconomic budget constraint is now given by $(1 - \bar{\tau})Y = C + I$.

To obtain long-run equilibrium values of the related variables, one can start with the definition of the steady-state as follows: The definition of the steady state implies that capital per unit of effective labor no longer grows at the steady state, that is, its growth rate does not change with time, $\dot{\check{k}}^s = 0$.¹¹⁷ Thence, using this definition in Eq. (A3) and assuming the existence of a steady state, one can obtain the steady-state value of effective capital per worker as¹¹⁸

$$\check{k}^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{1-\vartheta}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \quad (\text{A4})$$

and the steady state values of output and consumption in effective labor terms are easily obtained by substituting $\check{k}^s$ in the definitions of these equations, $\check{y}_t = \check{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}}$ and $\check{c}_t = (1 - s_K) \cdot (1 - \bar{\tau}) \cdot \check{k}_t^{\frac{\alpha}{1-\vartheta}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta}}$.

¹¹⁶ A dot over a variable shows the time derivative of that variable.

¹¹⁷ The superscript s stands for defining the steady-state values of the variables.

¹¹⁸ Note that the solution also requires that $\alpha + \vartheta \neq 1$.

$$\tilde{y}^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \quad (\text{A5})$$

$$\tilde{c}^s = (1-s_K)(1-\bar{\tau}) \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \quad (\text{A6})$$

Finally, Eqs. (A4)–(A6) are transformed into per-worker terms by multiplying each side of the equations by T_t ($= T_0 \cdot e^{\omega t}$) as follows:

$$k^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{1-\vartheta}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A7})$$

$$y^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A8})$$

$$c^s = (1-s_K)(1-\bar{\tau}) \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A9})$$

$$g^s = \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A10})$$

Eqs. (A7)–(A10) show that per-worker equilibrium values of physical capital, output, consumption, and government expenditures all grow at a constant rate of technological progress ω in the long run. The long-run equilibrium solutions of the augmented model further show that an increase in the parameter ϕ_H has a positive effect on the long-run equilibrium values of the related variables, $\frac{\partial k^s}{\partial \phi_H} > 0$, $\frac{\partial y^s}{\partial \phi_H} > 0$, $\frac{\partial c^s}{\partial \phi_H} > 0$, and $\frac{\partial g^s}{\partial \phi_H} > 0$. In other words, increasing the proportion of healthy workers in the labor force increases the stock of physical capital and, as a result, increases per-worker output and consumption in the long run. Furthermore, by taking the partial derivative of consumption per worker in Eq. (A8) with respect to the income tax rate, one can show that the golden rate of income tax that optimizes consumption per worker at the steady state is $\bar{\tau}^* = \vartheta$.

$$\begin{aligned} \frac{\partial c^s}{\partial \bar{\tau}} = & \left[(1-s_K)(1-\bar{\tau}) \left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta} \right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}} \cdot T_0 \cdot e^{\omega t} \right] \cdot \\ & \left[-\frac{1}{1-\bar{\tau}} - \frac{\alpha}{1-\vartheta-\alpha} \cdot (1-\bar{\tau})^{-1} + \frac{\vartheta}{1-\vartheta-\alpha} \cdot \bar{\tau}^{-1} \right] \end{aligned} \quad (\text{A11a})$$

$$\frac{\partial^2 c^s}{\partial \bar{\tau}^2} = \left[(1 - s_K)(1 - \bar{\tau}) \left(\frac{s_K(1 - \bar{\tau})}{n + \omega + \delta} \right)^{\frac{\alpha}{1 - \vartheta - \alpha}} \cdot \phi_H^{\frac{1 - \alpha}{1 - \vartheta - \alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1 - \vartheta - \alpha}} \cdot T_0 \cdot e^{\omega t} \right] \cdot \left[\frac{[\bar{\tau}^2(\bar{\tau} - 1)^2][(\alpha + \vartheta - 1)(\bar{\tau}^2 - 2\vartheta\bar{\tau} + \vartheta) + (\vartheta - \bar{\tau})^2]}{(\alpha + \vartheta - 1)^2} \right] > 0 \quad (\text{A11b})$$

Taking the natural log of Eq. (A8) also gives the long-run determinants of real output per worker, one of which is now the share of healthy workers in the total labor force stock:

$$\ln(y^s) = \left(\frac{\alpha}{1 - \vartheta - \alpha} \right) \ln(s_K) + \left(\frac{\alpha}{1 - \vartheta - \alpha} \right) \ln(1 - \bar{\tau}) - \left(\frac{\alpha}{1 - \vartheta - \alpha} \right) \ln(n + \omega + \delta) + \left(\frac{1 - \alpha}{1 - \vartheta - \alpha} \right) \ln(\phi_H) + \left(\frac{\vartheta}{1 - \vartheta - \alpha} \right) \ln(\bar{\tau}) + \ln(T_0) + \omega t \quad (\text{A12})$$

Parallel to the primary aim of this study, the following derivations are done to obtain a convergence equation conditional on the rates of healthy workers and the income tax rate. To this end, first, the fundamental equation of economic growth in Eq. (A3) is re-expressed in terms of income per unit of effective labor $\check{y}_t$: (i) from the intensive form of the production function, one can obtain that $\check{k}_t = \check{y}_t^{\frac{1 - \vartheta}{\alpha}} \cdot \phi_H^{\frac{\alpha - 1}{\alpha}} \cdot \bar{\tau}^{\frac{-\vartheta}{\alpha}}$, and (ii) the log-differentiation of the intensive form of the production function yields $\frac{1 - \vartheta}{\alpha} \frac{\dot{\check{y}}_t}{\check{y}_t} = \frac{\dot{\check{k}}_t}{\check{k}_t}$. Substituting these values in the growth form of Eq. (A3) gives the following nonlinear differential equation:

$$\frac{\dot{\check{y}}_t}{\check{y}_t} = \frac{\alpha}{1 - \vartheta} \left[s_K \cdot (1 - \bar{\tau}) \cdot \check{y}_t^{\frac{\alpha + \vartheta - 1}{\alpha}} \cdot \phi_H^{\frac{1 - \alpha}{\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{\alpha}} - (n + \omega + \delta) \right] \quad (\text{A13})$$

This differential equation in Eq. (A13) can be re-expressed as a univariate function of $\ln(\check{y}_t)$ as in Eq. (A14). After log-linearization, this equation also gives Eq. (A15).

$$\frac{d \ln(\tilde{y}_t)}{dt} = \frac{\alpha}{1-\vartheta} \left[s_K \cdot (1 - \bar{\tau}) \cdot \tilde{y}_t^{\frac{\alpha+\vartheta-1}{\alpha}} \cdot \phi_H^{\frac{1-\alpha}{\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{\alpha}} - (n + \omega + \delta) \right] \equiv \quad (\text{A14})$$

$$\psi[\ln(\tilde{y}_t)]$$

$$\frac{d \ln(\tilde{y}_t)}{dt} \approx \psi[\ln(\tilde{y}^s)] + \psi'[\ln(\tilde{y}^s)][\ln(\tilde{y}_t) - \ln(\tilde{y}^s)] \quad (\text{A15})$$

Substituting these values for $\psi[\ln(\tilde{y}^s)]$ and $\psi'[\ln(\tilde{y}^s)]$ in Eq. (A15) yields the following linear expression:

$$\frac{d \ln(\tilde{y}_t)}{dt} \approx - \left(\frac{1-\alpha-\vartheta}{1-\vartheta} \right) (n + \omega + \delta) [\ln(\tilde{y}_t) - \ln(\tilde{y}^s)] \quad (\text{A16})$$

Eq. (A16) is a log-linearization of Eq. (A14) around the steady-state position. In Eq. (A16), if λ is defined as $\lambda = \left(\frac{1-\alpha-\vartheta}{1-\vartheta} \right) (n + \omega + \delta)$, then it gives the convergence rate, which shows the rate at which an economy approaches its steady state. That is, $\frac{d(\tilde{y}_t/\tilde{y}^s)}{d \ln(\tilde{y}_t)} \cong -\lambda$.

To solve this linear differential equation in Eq. (A16), let define $\ln(\tilde{y}_t) = \eta_t$, $\lambda \cdot \ln(\tilde{y}^s) = a$, and $\dot{\eta}_t = -\lambda \cdot \eta_t + a$ as in Eq. (A16) and use integrating factor method as $\dot{\eta}_t \cdot e^{\lambda t} + \lambda \cdot \eta_t \cdot e^{\lambda t} = a \cdot e^{\lambda t}$, which is equal to $\frac{d(\eta_t \cdot e^{\lambda t})}{dt} = a \cdot e^{\lambda t}$. Hence, taking the integral of both sides $\int d(\eta_t \cdot e^{\lambda t}) = \int a \cdot e^{\lambda t} \cdot dt$ and a simple substitution for the original variables give the following equation:

$$\ln(\tilde{y}_t) = \ln(\tilde{y}^s) + c \cdot e^{-\lambda t} \quad (\text{A17})$$

where c is an arbitrary constant of integration. To derive an output convergence equation between two time periods, following Islam (1995), assume that t_1 and t_2 are two points in time such that $t_2 > t_1$ and $\tau = t_2 - t_1$. For $t = t_1$ that considers the log of real output per worker in the previous period, the value of the constant in Eq. (A17) is calculated as follows: $c = [\ln(\tilde{y}_{t_1}) - \ln(\tilde{y}^s)] e^{\lambda t_1}$. Hence, substituting the value of the constant for $t = t_2$ in Eq. (A17) further yields $\ln(\tilde{y}_{t_2}) = \ln(\tilde{y}^s) + [\ln(\tilde{y}_{t_1}) - \ln(\tilde{y}^s)] e^{\lambda t_1} \cdot e^{-\lambda t_2}$ or after rearranging,

$$\ln(\tilde{y}_{t_2}) - \ln(\tilde{y}_{t_1}) = -(1 - e^{-\lambda\tau})\ln(\tilde{y}_{t_1}) + (1 - e^{-\lambda\tau})\ln(\tilde{y}^s) \quad (\text{A18})$$

Finally, by converting Eq. (A18) into per-worker terms and substituting the value of $\ln(\tilde{y}^s)$ in Eq. (A18), one can get Eq. (A19):

$$\begin{aligned} \ln\left(\frac{Y_{t_2}}{L_{t_2}}\right) - \ln\left(\frac{Y_{t_1}}{L_{t_1}}\right) - \ln(T_{t_2}) + \ln(T_{t_1}) = & -(1 - e^{-\lambda\tau})\ln\left(\frac{Y_{t_1}}{L_{t_1}}\right) + \\ & (1 - e^{-\lambda\tau})\ln(T_{t_1}) + (1 - e^{-\lambda\tau})\ln\left(\left(\frac{s_K(1-\bar{\tau})}{n+\omega+\delta}\right)^{\frac{\alpha}{1-\vartheta-\alpha}} \cdot \phi_H^{\frac{1-\alpha}{1-\vartheta-\alpha}} \cdot \bar{\tau}^{\frac{\vartheta}{1-\vartheta-\alpha}}\right) \end{aligned} \quad (\text{A19})$$

After simplifications, the following standard output convergence equations are obtained that are commonly used in growth empirics:

$$\begin{aligned} \ln(y_{t_2}) - \ln(y_{t_1}) = & -(1 - e^{-\lambda\tau})\ln(y_{t_1}) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(s_K) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(1 - \bar{\tau}) - (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(n + \omega + \delta) + \\ & (1 - e^{-\lambda\tau})\left(\frac{1-\alpha}{1-\vartheta-\alpha}\right)\ln(\phi_H) + \\ & (1 - e^{-\lambda\tau})\left(\frac{\vartheta}{1-\vartheta-\alpha}\right)\ln(\bar{\tau}) + (1 - e^{-\lambda\tau})\ln(T_0) + \omega(t_2 - e^{-\lambda\tau}t_1) \end{aligned} \quad (\text{A20a})$$

or

$$\begin{aligned} \ln(y_{t_2}) = & (e^{-\lambda\tau})\ln(y_{t_1}) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(s_K) + (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(1 - \bar{\tau}) - (1 - e^{-\lambda\tau})\left(\frac{\alpha}{1-\vartheta-\alpha}\right)\ln(n + \omega + \delta) + \\ & (1 - e^{-\lambda\tau})\left(\frac{1-\alpha}{1-\vartheta-\alpha}\right)\ln(\phi_H) + (1 - e^{-\lambda\tau})\left(\frac{\vartheta}{1-\vartheta-\alpha}\right)\ln(\bar{\tau}) + \\ & (1 - e^{-\lambda\tau})\ln(T_0) + \omega(t_2 - e^{-\lambda\tau}t_1) \end{aligned} \quad (\text{A20b})$$

Eqs. (A20a) and (A20b) are the conditional output convergence equations that show the role of a healthy labor force and the income tax rate on economic growth and on the log of real output per worker, respectively. Hence, although both test conditional convergence, the former one (A20a) is used in the empirical estimations of this study to show the effects of a healthy workforce on output growth, as the latter empirically refers more to development levels than growth.

APPENDIX 2: The Social Planner's Solution for the Extended Ramsey Model with Personal Health Expenditures

The optimal control problem of a social planner can be written as follows:

$$\begin{aligned} \text{Max. } U(\check{c}_{Ht}, \check{c}_{Ot}) &= \int_0^\infty e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} ((\check{c}_{Ht})^a (\check{c}_{Ot})^{1-a})^{1-\theta} - 1}{1-\theta} \cdot dt \\ \text{s.t. } \dot{\check{k}}_t &= (1 - \bar{\tau}) \check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} - \check{c}_{Ht} - \check{c}_{Ot} - (n + \omega + \delta) \check{k}_t \end{aligned} \quad (\text{A21})$$

The present-value Hamiltonian and FOCs for a maximum of U are given by

$$J = e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} ((\check{c}_{Ht})^a (\check{c}_{Ot})^{1-a})^{1-\theta} - 1}{1-\theta} + \xi_t \{ (1 - \bar{\tau}) \check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} - \check{c}_{Ht} - \check{c}_{Ot} - (n + \omega + \delta) \check{k}_t \} \quad (\text{A22})$$

$$\begin{aligned} \frac{\partial J}{\partial \check{c}_{Ht}} = 0 &\Rightarrow \frac{e^{-(\rho-n)t} e^{(1-\theta)\omega t} a ((\check{c}_{Ht})^a (\check{c}_{Ot})^{1-a})^{1-\theta}}{\check{c}_{Ht}} = \\ & - \xi_t \left\{ \frac{(1-\bar{\tau}) \check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} \gamma(1-\alpha)}{\check{c}_{Ht}} - 1 \right\} \end{aligned} \quad (\text{A23})$$

$$\frac{\partial J}{\partial \check{c}_{Ot}} = 0 \Rightarrow \frac{e^{-(\rho-n)t} e^{(1-\theta)\omega t} (1-a) ((\check{c}_{Ht})^a (\check{c}_{Ot})^{1-a})^{1-\theta}}{\check{c}_{Ot}} = \xi_t \quad (\text{A24})$$

$$\dot{\xi}_t = -\frac{\partial J}{\partial \check{k}_t} \Rightarrow \dot{\xi}_t = -\xi_t \{ (1 - \bar{\tau}) \alpha \check{k}_t^{\alpha-1} (\check{c}_{Ht})^{\gamma(1-\alpha)} - (n + \omega + \delta) \} \quad (\text{A25})$$

$$\dot{\check{k}}_t = \frac{\partial J}{\partial \xi_t} \Rightarrow \dot{\check{k}}_t = (1 - \bar{\tau}) \check{k}_t^\alpha (\check{c}_{Ht})^{\gamma(1-\alpha)} - \check{c}_{Ht} - \check{c}_{Ot} - (n + \omega + \delta) \check{k}_t \quad (\text{A26})$$

and the transversality condition is $\lim_{t \rightarrow \infty} (\xi_t \cdot \check{k}_t) = 0$.

To check the existence of the steady state and its consistency with equilibrium conditions, first, one can show that $\frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$ if $\frac{d}{dt} \left(\frac{\xi^s}{\check{c}_H^s} \right) = 0$ in Eq. (A25). Second, using this result in the production function gives that $\frac{\dot{\check{y}}^s}{\check{y}^s} = \alpha \frac{\dot{\check{k}}^s}{\check{k}^s} + \gamma(1 - \alpha) \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$ and $\frac{\dot{\check{y}}^s}{\check{y}^s} = \frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$. From the ratio of Eqs. (A23) and (A24), one can also find that $\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} - \frac{\dot{\check{c}}_O^s}{\check{c}_O^s} = \frac{\dot{\check{y}}^s}{\check{y}^s}$. These findings imply that $(1 - \gamma) \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$ and $\frac{\dot{\check{y}}^s}{\check{y}^s} = \frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\gamma}{1-\gamma} \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$. Lastly, Eq. (A26)

provides that $\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} \left(\frac{\gamma(\check{c}_H^s + \check{c}_O^s) - \check{c}_H^s}{\check{c}_O^s} \right) = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s}$ if $\frac{d}{dt} \left(\frac{\check{k}^s}{\check{k}^s} \right) = 0$ and $\frac{\dot{\check{k}}^s}{\check{k}^s} = \gamma \frac{\dot{\check{c}}_H^s}{\check{c}_H^s}$. If these results are considered together, it can be clearly shown that the only condition that will ensure the simultaneous validity of these results is $\frac{\dot{\check{y}}^s}{\check{y}^s} = \frac{\dot{\check{k}}^s}{\check{k}^s} = \frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s} = 0$.

The solution to the model is as follows: First, if $\frac{\dot{\check{c}}_H^s}{\check{c}_H^s} = \frac{\dot{\check{c}}_O^s}{\check{c}_O^s} = 0$ is used in Eq. (A24), then it can be shown that $\frac{\dot{\xi}^s}{\xi^s} = -\rho + n + (1 - \theta)\omega$. Using this information in Eq. (A25) gives that $\check{c}_H^s = \left(\frac{(\rho + \theta\omega + \delta)}{(1 - \bar{\tau})\alpha} \right)^{\frac{1}{\gamma(1 - \alpha)}} (\check{k}^s)^{\frac{1}{\gamma}}$. From the production function, one can find that $\frac{\dot{\check{y}}^s}{\check{k}^s} = \left(\frac{(\rho + \theta\omega + \delta)}{(1 - \bar{\tau})\alpha} \right)$. The ratio of Eqs. (A23) and (A24) also provides that $\check{c}_O^s = -(1 - \bar{\tau})\check{y}^s\gamma(1 - \alpha) \left(\frac{1 - a}{a} \right) + \left(\frac{1 - a}{a} \right) \check{c}_H^s$. Lastly, if $\frac{\dot{\check{k}}^s}{\check{k}^s} = 0$, then Eq. (A26) shows that $(1 - \bar{\tau}) \frac{\dot{\check{y}}^s}{\check{k}^s} - (n + \omega + \delta) = \frac{\dot{\check{c}}_H^s + \dot{\check{c}}_O^s}{\check{k}^s}$. Thus, using the above expressions obtained for $\frac{\dot{\check{y}}^s}{\check{k}^s}$, $\check{c}_O^s$, and $\check{c}_H^s$ in $(1 - \bar{\tau}) \frac{\dot{\check{y}}^s}{\check{k}^s} - (n + \omega + \delta) = \frac{\dot{\check{c}}_H^s + \dot{\check{c}}_O^s}{\check{k}^s}$ gives the long-run equilibrium value of effective capital per worker as follows:

$$\check{k}^s = \left(\frac{(1 - \bar{\tau})\alpha}{\rho + \theta\omega + \delta} \right)^{\frac{1}{(1 - \alpha)(1 - \gamma)}} \cdot \left(\frac{a[(\rho + \theta\omega + \delta) - \alpha(n + \omega + \delta)] + (1 - a)(1 - \alpha)\gamma(\rho + \theta\omega + \delta)}{\alpha} \right)^{\frac{\gamma}{1 - \gamma}} \quad (\text{A27})$$

Therefore, the long-run equilibrium values of other model variables in per capita terms can be given by

$$\check{k}^s = \left(\frac{(1 - \bar{\tau})\alpha}{\rho + \theta\omega + \delta} \right)^{\frac{1}{(1 - \alpha)(1 - \gamma)}}. \quad (\text{A28})$$

$$\left(\frac{a[(\rho + \theta\omega + \delta) - \alpha(n + \omega + \delta)] + (1 - a)(1 - \alpha)\gamma(\rho + \theta\omega + \delta)}{\alpha} \right)^{\frac{\gamma}{1 - \gamma}} \cdot T_0 \cdot e^{\omega t}$$

$$\check{y}^s = \left(\frac{(1 - \bar{\tau})\alpha}{\rho + \theta\omega + \delta} \right)^{\frac{\alpha + \gamma(1 - \alpha)}{(1 - \alpha)(1 - \gamma)}}. \quad (\text{A29})$$

$$\left(\frac{a[(\rho + \theta\omega + \delta) - \alpha(n + \omega + \delta)] + (1 - a)(1 - \alpha)\gamma(\rho + \theta\omega + \delta)}{\alpha} \right)^{\frac{\gamma}{1 - \gamma}} \cdot T_0 \cdot e^{\omega t}$$

$$c_H^s = \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+\delta} \right)^{\frac{1}{(1-\alpha)(1-\gamma)}} . \quad (A30)$$

$$\left(\frac{a[(\rho+\theta\omega+\delta)-\alpha(n+\omega+\delta)]+(1-a)(1-\alpha)\gamma(\rho+\theta\omega+\delta)}{\alpha} \right)^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t}$$

$$c_O^s = (1-a) \cdot \left(\frac{(1-\bar{\tau})\alpha}{\rho+\theta\omega+\delta} \right)^{\frac{1}{(1-\alpha)(1-\gamma)}} . \quad (A31)$$

$$\left(\frac{a[(\rho+\theta\omega+\delta)-\alpha(n+\omega+\delta)]+(1-a)(1-\alpha)\gamma(\rho+\theta\omega+\delta)}{\alpha} \right)^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t}$$

$$\left(\frac{(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)-\alpha(n+\omega+\delta)}{a[(\rho+\theta\omega+\delta)-\alpha(n+\omega+\delta)]+(1-a)(1-\alpha)\gamma(\rho+\theta\omega+\delta)} \right) \cdot T_0 \cdot e^{\omega t}$$

Finally, the long-run solution to the endogenously determined savings rate of the economy is given by

$$s^s = \frac{(1-\bar{\tau})y^s - c^s}{(1-\bar{\tau})y^s} = \frac{\alpha(n+\omega+\delta)}{(\rho+\theta\omega+\delta)} \quad (A32)$$

The solution of the above model requires that $\frac{1}{1-\alpha} > \gamma$ and $(\rho + \theta\omega + \delta) > \alpha(n + \omega + \delta)$, which is also consistent with the restriction required for the boundedness of the utility integral, *i.e.*, $(\rho - n) > (1 - \theta)\omega$.

APPENDIX 3: The Social Planner's Solution for the Extended Ramsey Model with Public Health Expenditures

The optimal control problem for a centralized economy can be written as follows:

$$\begin{aligned} \text{Max. } U(\check{c}_t, \check{g}_{Ht}) &= \int_0^\infty e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} ((\check{c}_t)^a (\check{g}_{Ht})^{1-a})^{1-\theta} - 1}{1-\theta} \cdot dt \\ \text{s.t. } \dot{\check{k}}_t &= (1 - \bar{\tau})\check{y}_t - \check{c}_t - (n + \omega + \delta)\check{k}_t \end{aligned} \quad (\text{A33})$$

The present-value Hamiltonian and FOCs for a maximum of U are given by

$$\begin{aligned} J &= e^{-(\rho-n)t} \frac{e^{(1-\theta)\omega t} \left((\check{c}_t)^a \left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}} \right)^{1-a} \right)^{1-\theta} - 1}{1-\theta} + \xi_t \left\{ (1 - \right. \\ &\left. \bar{\tau}) \left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - \check{c}_t - (n + \omega + \delta)\check{k}_t \right) \right\} \end{aligned} \quad (\text{A34})$$

$$\frac{\partial J}{\partial \check{c}_t} = 0 \Rightarrow \frac{e^{-(\rho-n)t} e^{(1-\theta)\omega t} a \left((\check{c}_t)^a \left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}} \right)^{1-a} \right)^{1-\theta}}{\check{c}_t} = \xi_t \quad (\text{A35})$$

$$\begin{aligned} \dot{\xi}_t &= -\frac{\partial J}{\partial \check{k}_t} \Rightarrow -\dot{\xi}_t = \\ &\left(\frac{e^{-(\rho-n)t} e^{(1-\theta)\omega t} (1-a) \left((\check{c}_t)^a \left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}} \right)^{1-a} \right)^{1-\theta}}{\left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}} \right)} \right) \cdot \\ &\left(\left(\frac{\alpha}{1-\gamma+\alpha\gamma} \right) (\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{1}{1-\gamma+\alpha\gamma}} \right) + \xi_t \left\{ (1 - \right. \\ &\left. \bar{\tau}) \left(\frac{\alpha}{1-\gamma+\alpha\gamma} \right) (\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - (n + \omega + \delta) \right\} \end{aligned} \quad (\text{A36})$$

$$\dot{\check{k}}_t = \frac{\partial J}{\partial \xi_t} \Rightarrow \dot{\check{k}}_t = (1 - \bar{\tau}) \left((\check{k}_t)^{\frac{\alpha}{1-\gamma+\alpha\gamma}} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - \check{c}_t - (n + \omega + \delta)\check{k}_t \right) \quad (\text{A37})$$

and the transversality condition is $\lim_{t \rightarrow \infty} (\xi_t \cdot \tilde{k}_t) = 0$.

First, by using Eqs. (A35) and (A36), one can show that $\frac{\dot{\xi}^s}{\xi^s} = \left(-\left(\frac{1-a}{a}\right) \frac{\dot{c}^s}{c^s} + (1-\bar{\tau})(\tilde{k}^s)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} \right) \left(\frac{\alpha}{1-\gamma+\alpha\gamma} \right) + (n+\omega+\delta)$. From the production function, it can be further shown that $\frac{\dot{y}^s}{y^s} = \left(\frac{\alpha}{1-\gamma+\alpha\gamma} \right) \frac{\dot{k}^s}{k^s}$. Eq. (A37) provides that $\frac{\dot{k}^s}{k^s} = (1-\bar{\tau})(\tilde{k}^s)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - \frac{\dot{c}^s}{c^s} - (n+\omega+\delta)$. Using the definition of the steady state, $\frac{d}{dt} \left(\frac{\xi^s}{\xi^s} \right) = 0$ and $\frac{d}{dt} \left(\frac{\tilde{k}^s}{\tilde{k}^s} \right) = 0$, in the above expressions gives that $\frac{\dot{k}^s}{k^s} = \frac{\dot{c}^s}{c^s} = \frac{\dot{y}^s}{y^s} = \frac{\dot{g}_H^s}{g_H^s} = 0$.

The long-run equilibrium solution of the model is as follows: Given that $\frac{\dot{k}^s}{k^s} = \frac{\dot{c}^s}{c^s} = 0$, Eq. (A35) provides $\frac{\dot{\xi}^s}{\xi^s} = -\rho + n + (1-\theta)\omega$. Using this finding gives that $\rho + \omega\theta + \delta = \left(\left(\frac{1-a}{a}\right) \frac{\dot{c}^s}{c^s} + (1-\bar{\tau})(\tilde{k}^s)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} \right) \left(\frac{\alpha}{1-\gamma+\alpha\gamma} \right)$. Eq. (A37) further shows that $(1-\bar{\tau})(\tilde{k}^s)^{\frac{\alpha}{1-\gamma+\alpha\gamma}-1} (x_H \bar{\tau})^{\frac{\gamma(1-\alpha)}{1-\gamma+\alpha\gamma}} - (n+\omega+\delta) = \frac{\dot{c}^s}{c^s}$. Hence, substituting the value of $\frac{\dot{c}^s}{c^s}$ in the preceding expressions directly yields that $\tilde{k}^s = \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}}$. As a result, at long-run equilibrium, per capita values of physical capital, consumption, income, and fiscal policy variables can be given as follows:¹¹⁹

$$k^s = \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A38})$$

$$c^s = \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{1-\gamma+\alpha\gamma}{(1-\alpha)(1-\gamma)}} \cdot \left(\frac{a[(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)-\alpha(n+\omega+\delta)]}{\alpha} \right) \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A39})$$

¹¹⁹ The model strictly requires that $(\rho + \theta\omega + \delta)(1 - \gamma + \alpha\gamma) > \alpha(n + \omega + \delta)$ and $\frac{1}{1-\alpha} > \gamma$.

$$y^s = \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A40})$$

$$g_H^s = \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H \bar{\tau})^{\frac{1}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A41})$$

$$g^s = taxr^s = (\bar{\tau})^{\frac{1}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A42})$$

$$g_O^s = (1 - x_H) \cdot (\bar{\tau})^{\frac{1}{1-\gamma}} \cdot \left(\frac{(1-\bar{\tau})\alpha}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right)^{\frac{\alpha}{(1-\alpha)(1-\gamma)}} \cdot (x_H)^{\frac{\gamma}{1-\gamma}} \cdot T_0 \cdot e^{\omega t} \quad (\text{A43})$$

and the equilibrium savings rate is as in Eq. (A44).

$$s^s = \left(\frac{\alpha(n+\omega+\delta)}{a(\rho+\theta\omega+\delta)(1-\gamma+\alpha\gamma)+\alpha(1-a)(n+\omega+\delta)} \right) \quad (\text{A44})$$

APPENDIX 4: The List of Sample Countries

Appendix Table 1: The List of Sample Countries

OECD (38)	LDCS (34)
Australia	Angola
Austria	Bangladesh
Belgium	Benin
Canada	Bhutan
Chile	Burkina Faso
Colombia	Burundi
Costa Rica	Cambodia
Czechia	Central African Republic
Denmark	Chad
Estonia	Comoros
Finland	Democratic Republic of Congo
France	Djibouti
Germany	Ethiopia
Greece	Gambia
Hungary	Guinea
Iceland	Guinea-Bissau
Ireland	Haiti
Israel	Lao People's Democratic Republic
Italy	Lesotho
Japan	Madagascar
Republic of Korea	Mali
Latvia	Mauritania
Lithuania	Mozambique
Luxembourg	Myanmar
Mexico	Nepal
Netherlands	Niger
New Zealand	Rwanda
Norway	Senegal
Poland	Sierra Leone
Portugal	Sudan
Slovakia	Tanzania
Slovenia	Togo
Spain	Uganda
Sweden	Zambia
Switzerland	
Turkey	
United Kingdom	
United States	